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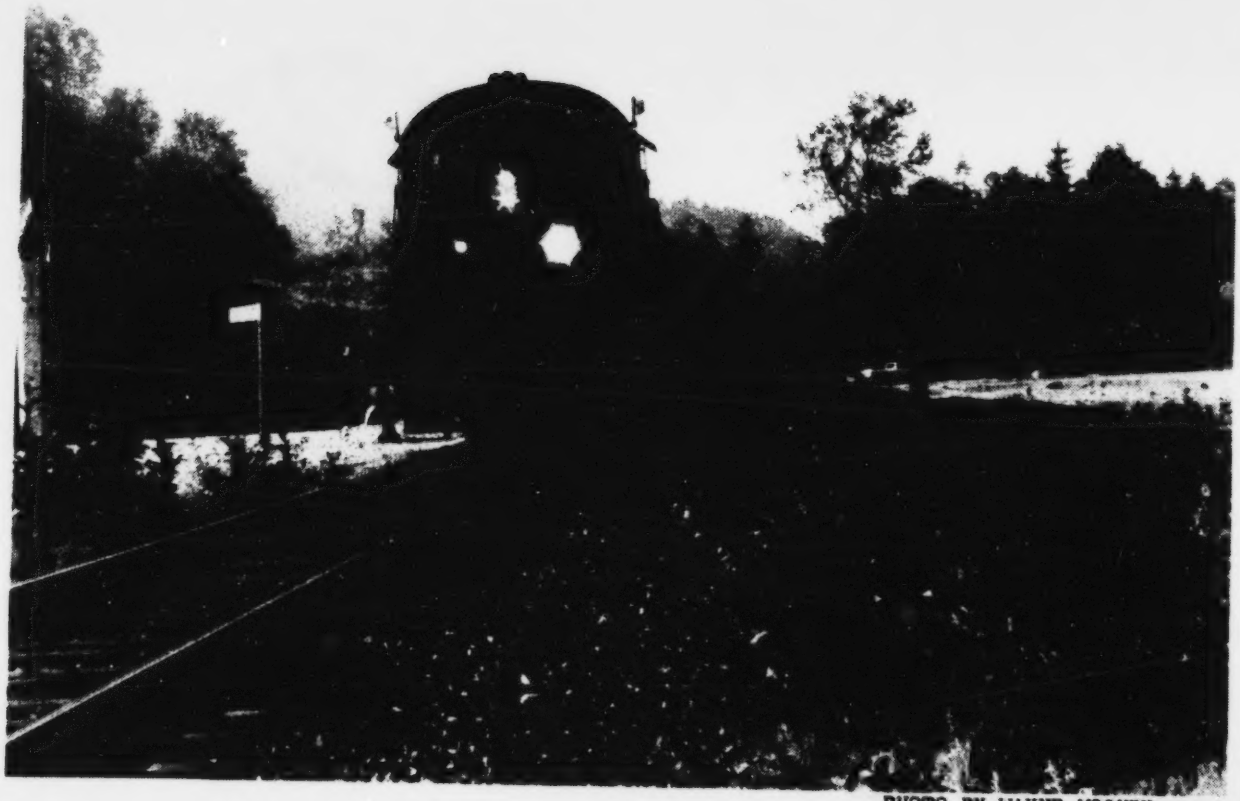

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LOCATION, IDENTIFICATION, AND CONTROL SYSTEM APPLICATION TO MAINLINE RAILROADS

Prepared For The
Transportation Development Centre
Of Transport Canada

By
Glenayre Electronics Ltd.

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October, 1983

Location, Identification, and Control System Application to Mainline Railroads

Final Report

by

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October 1983

Transport Canada / Transports Canada

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

This document reports the results of a study into the potential for application of the Location, Identification and Control System (LIC) to mainline railroads. It is shown that the capabilities of the present system must be expanded to mainline use, and several possible functional extensions to LIC are examined. To provide the power and flexibility needed to incorporate such extensions, the prototype Data Collection Processor (DCP) was redesigned around a standard microprocessor bus system. Laboratory tests and operational evaluation of the new DCP indicate that it meets the requirements of the present application and is capable of expansion.

To further establish the criteria for mainline LIC application, a site-specific study was carried out on a CP Rail line. A set of user requirements was then drawn up, and a detailed conceptual design for a mainline LIC System was prepared.

It is concluded that the LIC System is capable of expansion to meet the requirements of mainline railroads, although a large amount of additional engineering would be necessary. It is recommended that no further development work be done at this time and that extensions to the system be considered only in the event of specific customer interest.

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17. Résumé

Ce rapport rend compte des résultats de l'étude sur la possibilité de transposer le système LIC (Localisation, Identification et Commande de trains) aux voies ferroviaires principales. Etablissant la nécessité d'élargir les possibilités du système actuel pour qu'il puisse convenir à l'application nouvelle envisagée, le rapport examine certaines fonctions supplémentaires que le LIC pourra prendre en charge. En vue d'offrir une capacité de traitement accrue et une plus grande souplesse d'emploi, le processeur de données (DCP) a dû être réétudié; il utilisera dorénavant la technologie standard des bus et microprocesseurs. Les essais en laboratoire et l'évaluation en service de ce processeur ont montré qu'il satisfait aux exigences de son application actuelle et qu'il se prête à une extension de son domaine d'utilisation.

Afin d'affiner les critères de transposition du LIC, une étude sur le terrain a été faite par le Canadien Pacifique. Cette étude a permis de cerner les besoins des utilisateurs éventuels et elle a été suivie de l'étude détaillée du système envisagé.

Le rapport conclut que le LIC est transposable aux voies principales, mais que des études plus poussées sont nécessaires. Il termine en recommandant d'arrêter, pour le moment, le perfectionnement du système et de ne le reprendre que si un client s'y intéresse vraiment.

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Finally, we wish to thank Mr. N. A. MCPHERSON of British Columbia Railway and his staff, whose involvement with the LIC System has been both the foundation and an essential contribution to this project.

EXECUTIVE SUMMARY

Objectives

This document reports the results of a study of the potential for mainline railroad application of the Location, Identification, and Control (LIC) System.

Mainline System Definition

LIC is intended to increase the traffic handling capacity of lines currently under train order or Manual Block System (MBS) control. The predicted growth in coal traffic on both CP Rail and Canadian National lines of this type points to the imminent need for such a system.

While the present LIC implementation on British Columbia Railway meets the requirements of a secondary line, the System must be expanded to include features essential to mainline operation. Three areas for expansion were considered:

- Traffic Control
- Computer-aided Dispatching
- Automatic Train Protection

Functional Extensions To LIC

Several candidate functional extensions to LIC were examined in detail:

1) Remote activation of train brakes.
2) Communication of speed limit information to the ELUs.
3) Overspeed detection and subsequent penalty brake application.
4) Prediction of braking distance.
5) Automatic braking after warning.
6) "DO NOT PASS" and "ILLEGAL ENTRY" cab display warnings.
7) Remote control of switch points.

Data Collection Processor Development

In order to accommodate the above functional extensions, the LIC Data Collection Processor (DCP) must be expanded significantly beyond its original design. The preliminary DCP used in the LIC prototype development phase showed a number of flaws which limited its capacity for expansion, and a complete redesign was undertaken. The new design is based on the Intel Multibus (tm) system and employs bought-out circuit boards wherever possible. The Z-80 microprocessor was retained in the new DCP, which can address up to 1 megabyte of memory and supports a wide variety of I/O interfaces.

The structured software design process emphasized program safety. Most task modules were coded in Pascal/Z, and the system runs under a modified version of the AMX real-time multitasking operating system.

The redesigned DCP was constructed to meet the requirements of British Columbia Railway. Both memory and I/O ports can be expanded simply through the addition of extra circuit cards; thus it should be possible to reconfigure the DCP for mainline application. If additional processing power is required, e.g., to incorporate power switch control, the Multibus structure can support multiple processors.

DCP Evaluation

DCP hardware tests revealed some timing problems which were corrected in the laboratory; no further hardware problems were encountered in the field. The DCP software was tested exhaustively from the module to the system level.

Operational evaluation of the redesigned DCP was conducted in late 1982 as part of the British Columbia Railway's LIC Full Tracking tests. The tests covered four areas: transponder reporting, odometer calibration, communications coverage, and train location. The new DCP design was found to meet all requirements of flexibility and ease of maintenance and to handle its processing load well. The DCP appears capable of expansion to include additional tasks.

Mainline Railroad Study

To further define the criteria for the application of LIC to mainline operations, a study was undertaken of Canadian Pacific's Fording River, Cranbrook, and Windemere subdivisions. Unit coal train traffic on these lines is expected to increase

significantly, exceeding the capacity of the present train-order control system. The study investigated the line profile, present and projected traffic, and current operating procedures. Particular attention was paid to the potential for automation of almost 90% of the train dispatcher's workload.

Mainline User Requirements

The Canadian Pacific Rail study led to the definition of the following user requirements for mainline LIC application:

- Full train control from a central dispatch office.
- Capacity of 35 trains per day; up to 20 at any one time.
- Precise graphics display of train location and status.
- Locomotive cab display giving engineman "electronic vision" of conditions ahead.
- Remote control of power switches.
- Absolute permissive block control between sidings on single track.
- Automatic train protection of braking after warning type.
- Cab display and system monitoring of speed limits to prevent overspeed.
- Computer-aided train control to provide automatic route clearance, meet and pass scheduling, and conflict prediction.
- Comprehensive dispatcher information system.
- Remote emergency brake application under dispatcher control.
- Allowance for operation of LIC and non-LIC equipped trains.

Conceptual Design For Mainline Railroads

A detailed conceptual design for mainline LIC application was prepared on the basis of the above requirements.

1) Traffic Control

   - LIC uses fixed block control in conjunction with cab display indications to authorize train movements.

   - Block limits or Control Points (CPs) are marked by DIGITRAC transponders; train location within a block is determined by locomotive odometer.

   - LIC uses absolute permissive block control between sidings. The system automatically protects against authorization of unsafe movements.

- Remote control of power switches is provided by means of a LIC Radio Switch Controller Unit (RSCU). A functional description of the RSCU is appended to this report.

- A colour graphics display provides the dispatcher with a record of the current status of all blocks, switches, control points, and trains.

- The system provides for smooth handover of trains between adjacent LIC territories and between LIC and CTC territories.

2) Automatic Train Protection

- LIC monitors train location and speed and causes an audible alarm in the engine cab:
  - at a computed stopping distance from a restriction;
  - in the event that train speed exceeds the current limit.

  If the warning is ignored, LIC automatically initiates a penalty brake application.

- The cab display shows both train speed and speed limit. The DCP transmits the current speed limit to each train according to its location; train speed is returned by the ELU.

- The dispatcher may initiate an emergency brake application on a specified train if necessary.

3) Automated Train Dispatching

- Computer-aided control automatically issues authorities and lines switches to expedite train movement. System analyzes train characteristics and requirements to optimize meets and passes. Track occupancy limits are protected against illegal entry.

- The dispatcher information system, based on the automated train sheet, assumes most routine clerical tasks and provides for:
  - entry and/or display of all data relevant to train movement;
  - generation of a variety of printed reports for both immediate and historical use;
  - efficient management of train crews.

Conclusions

1) The LIC System is capable of expansion to meet the requirements of mainline railroad application.

2) The existing LIC installation at British Columbia Railway is capable of handling up to 10 trains simultaneously. Factors which affect system capacity are:

   - Radio coverage
   - Communications data rate
   - DCP capacity
   - Dispatcher interface capacity

3) Three applications of subsets of the LIC System are presented as alternatives to implementation of the full system:

   - the Host computer, graphics display, and terminals as a dispatcher aid in Manual Block System operations;

   - real-time monitoring of data from moving trains via the LIC radio link;

   - highly precise train location and speed information overlaid on conventional CTC.

Recommendations

1) No further development work should be done on the LIC System.

2) Purchasers of the existing system or subsets thereof should be vigorously pursued.

3) Extensions to LIC should not be considered without genuine customer interest and full funding.

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1. INTRODUCTION

1.1 Background

Since 1975, GLENAYRE Electronics Ltd. and British Columbia Railway have been engaged in an ongoing program to develop the Location, Identification and Control (LIC) System for railway traffic management. The development of this technology has been made possible by the active support and participation of the Transportation Development Centre (TDC), Transport Canada.

The LIC System employs track and train instrumentation to generate data to feed a train-mounted microcomputer, communicating via radio links with a central computer in the dispatch office. By these means train operating parameters are monitored automatically and displayed for the information of the dispatcher who can then authorize train movement instructions to be transmitted in the locomotive cab.

The technological feasibility of LIC signalling was demonstrated in 1978 after the installation of a trial system on the British Columbia Railway Squamish subdivision. At present, TDC is participating with the British Columbia Ministry of Economic Development, British Columbia Railway, and GLENAYRE in the installation of an operational LIC System on the 154 mile Squamish subdivision. At this stage, now that a specific implementation has been finalized, it is appropriate to review the broad requirements for future applications of LIC.

Although early work on definition and specification of LIC was done with the involvement of both Canadian National and Canadian Pacific Railway, the necessity of the essential developmental step to provide LIC operation on British Columbia Railway has not allowed the incorporation of features that are required for mainline railway service.

There are some potential areas of difficulty with the LIC concept, particularly in tracking the progress of the rear of the train. If railroads are turning toward ending the use of the caboose and tail-end crew, then alternatives to the present British Columbia Railway system must be considered even at this early stage.

There is also something of a system concept problem with the inclusion of power switches. Power must be run into the siding for the switch, and this erodes the price advantage of the LIC System. Further, to lock the switch by conventional means, a track circuit is required at the switch.

Yet another consideration related to the use of track circuits is that of crossing protection. It is questionable whether crossing protection should be considered in any way part of LIC.

1.2 Objectives and Scope

The purpose of this document is to summarize the work done to identify and provide design solutions for the additional requirements which must be met for the installation of LIC on a mainline railway.

The work was carried out by GLENAYRE Electronics according to the contract work statement which states the specific objective as:-

> Initial study and software design to evaluate the feasibility of utilizing the LIC System on the Fording River and Windemere subdivisions of Canadian Pacific Rail between Fording and Golden, British Columbia.

The project commenced this process with a study of the application of the Data Collection Processor and the train on-board equipment in terms of the broad spectrum of application to mainline National Railroads. This phase of work involved implementation of a selected set of applications software and subsequent field testing at British Columbia Railway.

The site specific study into Canadian Pacific Railway's Fording to Golden operations was carried out to evaluate the feasibility of LIC for this particular application. The preparation of operating scenarios and evaluation of dynamics as called for by the work statement were not carried out. This was as a direct result of the original cutback in project budget which caused the effort to be foreshortened.

However, a conceptual design was prepared for the use of LIC as a mainline railway traffic management system on Canadian Pacific Rail.

This report represents the final step in completing the requirements of the contract.

1.3 Report Outline

Part 2 is a brief description of the purpose and general operation of the LIC System.

Part 3 outlines the scope of applications of LIC as defined by consultation with Canadian Pacific Railway, Canadian National Railway, VIA Rail, and other selected companies. This part presents a definition of a LIC System for mainline railroads which describes the requirements of such a system and the concepts used to achieve these requirements, and summarizes the operation of the proposed system.

Part 4 discusses functional extensions to the present LIC System which if incorporated would give a comprehensive railway traffic control system for moderate to heavy traffic lines.

Part 5 describes in detail the development work carried out on the Data Collection Processor (DCP) hardware, the specification and implementation of safety programming and the restructuring of existing software, and the provision of a new operating system. Also described are the programming language and design techniques together with the program generation facilities.

Part 6 describes the procedures used to evaluate the new DCP design and presents the results of operational tests carried out at British Columbia Railway with the new design.

Part 7 is a site specific study of Canadian Pacific Railway line between Fording and Golden, in southeastern British Columbia. Discussed are the line profile and traffic, present operating procedures, and various studies pertinent to the application of LIC to such a line.

Part 8 summarizes the user requirements for mainline LIC application as derived from the above study.

Part 9 is devoted to the conceptual design proposed for LIC on Canadian Pacific Rail.

Part 10 presents the conclusions drawn from the work carried out and makes recommendations for further work.

2. LIC SYSTEM SUMMARY

2.1 Purpose of LIC

Much of Canada's mainline railroad mileage is unprotected by wayside signalling of any form. This lack results largely from the high cost per mile of installation relative to the level of traffic. The movement of trains on these lines is usually controlled either by timetable and train order or by Manual Block System (MBS).

Train order operation and MBS operation differ considerably, although under both systems a subdivision is placed in the hands of a centrally located dispatcher who uses the timetable as the basic schedule of movements.

Under the train order system, regular trains are authorized by timetable schedule and extra trains by train order. Trains run with respect to one another according to rules which determine their relative superiority. An inferior train must clear the time of all superior trains and, if unable to do so in the prescribed manner, must provide flag protection against both opposing and following movements. In order to expedite the movement of trains, the dispatcher may issue train orders to restrict superior trains and give additional rights to inferior trains.

In train order territory, then, trains are separated from one another by superiority and time. Operational efficiency can suffer when a superior train is unable to maintain its timetable schedule. The train order system has two chief drawbacks, both of which become more significant with increased traffic. First, while the train dispatcher may issue orders to expedite train movement, he may do so only at an open train order office. Second, if an interior train is unable to clear the time of a superior train, the only prescribed means of protection is by flagman.

By contrast, the Manual Block System separates trains by space interval. Train movements are authorized by MBS Clearances which supersede the superiority of trains for both opposing and following movements on the same track. At any one time a train has exclusive possession of a block of track, subject to restrictions concerning specified meets and passes. Flag protection is not required under MBS except where two or more trains have been authorized to occupy or proceed within the same limits.

The exclusive block of MBS offers inherently greater protection than do the time and superiority rules of train order operation. Manual block is primarily a safety rather than capacity increasing feature, the main limitation of the system being block length. The usual minimum block is between stations, a distance of 5 to 15 miles. Clearly, once a train enters a block that section of track can be tied up for a considerable time.

On light traffic lines with long headways, train safety is not appreciably different under train order or manual block systems. Selection of one or the other has been mainly a matter of company policy. In its earlier stages manual block required the installation of wayside signals and operators for every block, whereas train order operation merely required operators at specified stations. Thus, despite the inherent safety of manual block, train order operation was economically more attractive.

As traffic density increases, however, it can be seen that a space separation scheme has greater potential, provided the blocks can be shortened to a more efficient length. To meet this provision two further requirements must be met: first, trains must be precisely located so that spacings can be maintained to ensure safety; and second, a means to operate without remote operators must be found.

Track circuit signalling was the solution to both problems. It overcame most of the limitations of MBS by automatic actuation of the signals by the trains themselves. This system, known as Automatic Block Signalling (ABS), together with electric interlocking led to the development of Centralized Traffic Control (CTC) in 1927. Track circuit systems proved to be expensive as a result of the need for extensive wayside installations including power and telegraph along the entire route. When one considers the distances and terrain involved on many Canadian main lines it is not surprising that MBS and train order and timetable operation are still common.

Track to train radio communication has attained extensive use on Canadian railways and has been used to implement a form of Manual Block System which obviates or at least minimizes the need for remote operators. Without wayside signals, the system relies on voice communication of authorities to proceed through or occupy blocks of variable length determined by the dispatcher. In this way MBS can be implemented with little more than a suitable communication system. The original traffic capacity limitation is not overcome, however, and, because the dispatcher must rely solely upon the train crew for location information, the system is not inherently as safe as its traditional counterpart.

It can be seen that what was required was a system which could improve the capacity of voice dispatch MBS operation at minimum cost. These basic requirements were met by a base-line LIC system which provided the dispatcher with precise location and identity information for all trains in his territory. This system permits efficient train control by voice dispatch of movement authorities over the track to train radio system. Furthermore, blocks lengths could be shortened, and the dispatcher could ensure safety by applying absolute and permissive blocking for opposing and following movements, respectively. The high cost of track circuits was avoided through the use of passive electronic wayside position markers as a means to determine train location.

Enhancement of the base-line LIC system with cab signalling provided the capability for centrally controlled manual block operation. This train-borne system, using microprocessor control and digital data radio communications, provides state of the art manual block signalling independent of traditional wayside installations. The system exploits the inherent safety concepts of MBS to safeguard the movement of trains. This system represents the present limit of LIC development in the form of the operational system being installed on B.C. Railway.

For main line applications, however, the manual block LIC system will have to be enhanced to increase traffic handling capacity. In addition, the safety of trains would have to be improved through better use of LIC's on-board intelligence.

2.2 System Description

In the LIC system, the control centre coordinates mobile train-borne equipment with a system of fixed wayside movement Control Points (CPs).

The positions of Control Points are chosen to create a series of fixed blocks, the lengths of these blocks being dependent upon geographical location, maximum service braking distance, and traffic density. In order to provide route control at sidings and junctions, each main track switch is designated as a Control Point.

Each control point is marked by the installation of two or three DIGITRAC passive wayside transponders uniquely coded to correspond with geographical location (Fig. 1). On-train equipment interrogates the transponders to determine train location, and the resulting information is automatically passed by radio to the control centre. An independent electronic locomotive odometer gives continuous location within the block to an accuracy of 0.01 mile.

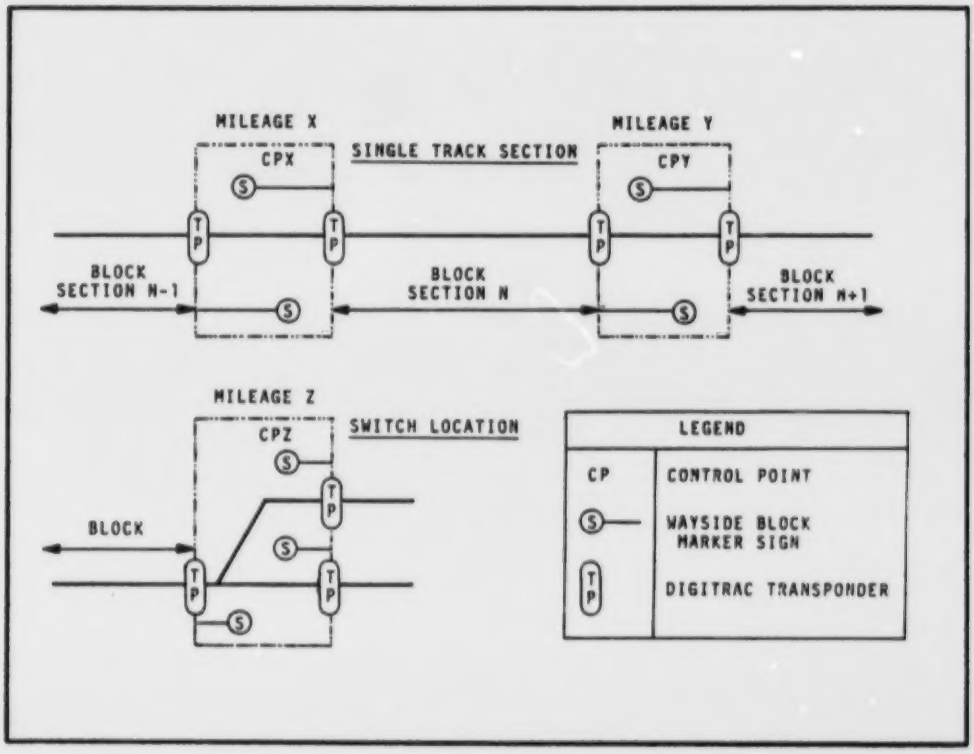
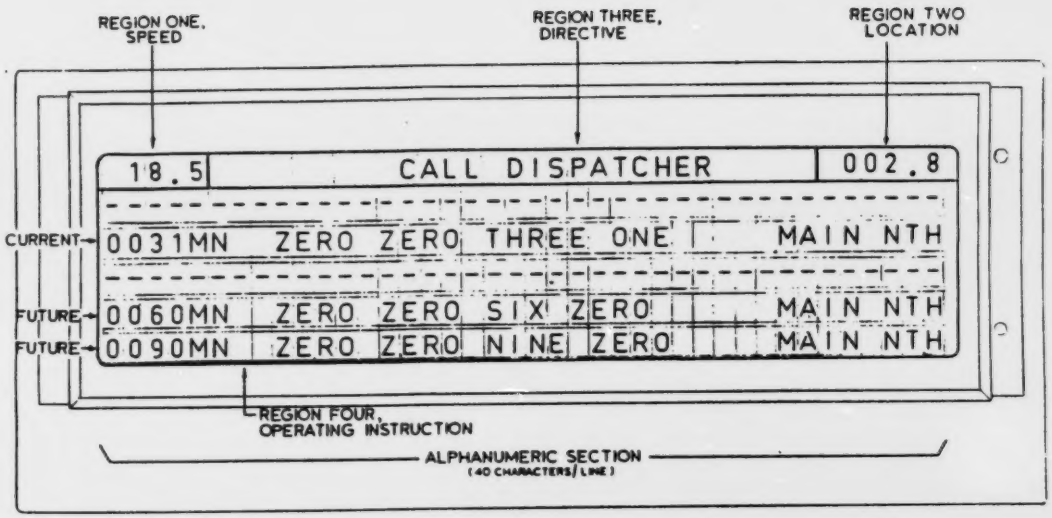


FIGURE 1 - Transponder Positions and Block Configurations

The control centre processor stores fixed data relating to track geometry and grades, control block structure, and other parameters. This information is used in conjunction with train derived location, direction, and speed to compute train movement commands. The commands are then transmitted over the data radio network to the relevant train. The on-board processor subsequently validates the commands before forwarding them to a cab signal control display.

Visual presentation of the commands take the form of plain language movement authorities giving the route and block authorized for movement, supplemented by special directives and a digital readout of both speed and subdivision mileage. In addition to the current block authority the display also shows whether authority to proceed over the next two blocks ahead has been granted. Thus the LIC cab display maintains three block signalling. As the engineman has a direct readout of location he can operate on the "electronic vision" principle (Fig. 2).

Ultimate control of the train in accordance with the transmitted commands is the responsibility of the engineman. The results of his actions are continually monitored by the system. If a command is violated and thereby jeopardizes the safety of his or another train, LIC will alert the engineman to the unsafe condition. If the situation remains uncorrected, the system will cause an automatic brake application to slow or stop the train as required.



OTHER POSSIBLE DISPLAY FORMATS FOR REGION FOUR (OPERATING INSTRUCTION)

1056 SW ONE ZERO FIVE SIX	---- SWG
1056RS ONE ZERO FIVE SIX	RSTR SOU
1056SN ONE ZERO FIVE SIX	SIDE NTH
Abbreviated Inst. Control Point	Routing Direction

FIGURE 2 - Location Identification and Control Cab Display

The flow of data between the LIC command centre and its associated peripherals and field equipment is shown in simplified form in Fig. 3. The equipment architecture comprises three major systems: the central control system (CCS); the train borne system (TBS); and the data communications system.

The Central Control System consists of a Data Collection Processor (DCP) and a minicomputer (Host) that together monitor and control system operation. The CCS repeatedly polls active train processors to derive the location and identification data which allow precise tracking of train movements. This information then enables computation of safe movement authorities which are communicated to the in-cab signalling system.

The train-borne system consists of an on-board microprocessor; the train locating interrogator and reader; the locomotive odometer or distance measuring system; an electronic cab display; and an interface with the mobile data radio system.

The communications system is the backbone of LIC operations. It comprises a mobile data radio network feeding into a microwave communications trunk through remote drop repeater sites. All train data and controls are routed through this track to train radio systems.

The three systems are designed to operate around the railway system infrastructure and are dependent on the DIGITRAC System of train location.

The system equipment in conjunction with LIC operating rules is designed to obtain the highest possible degree of safety and efficiency.

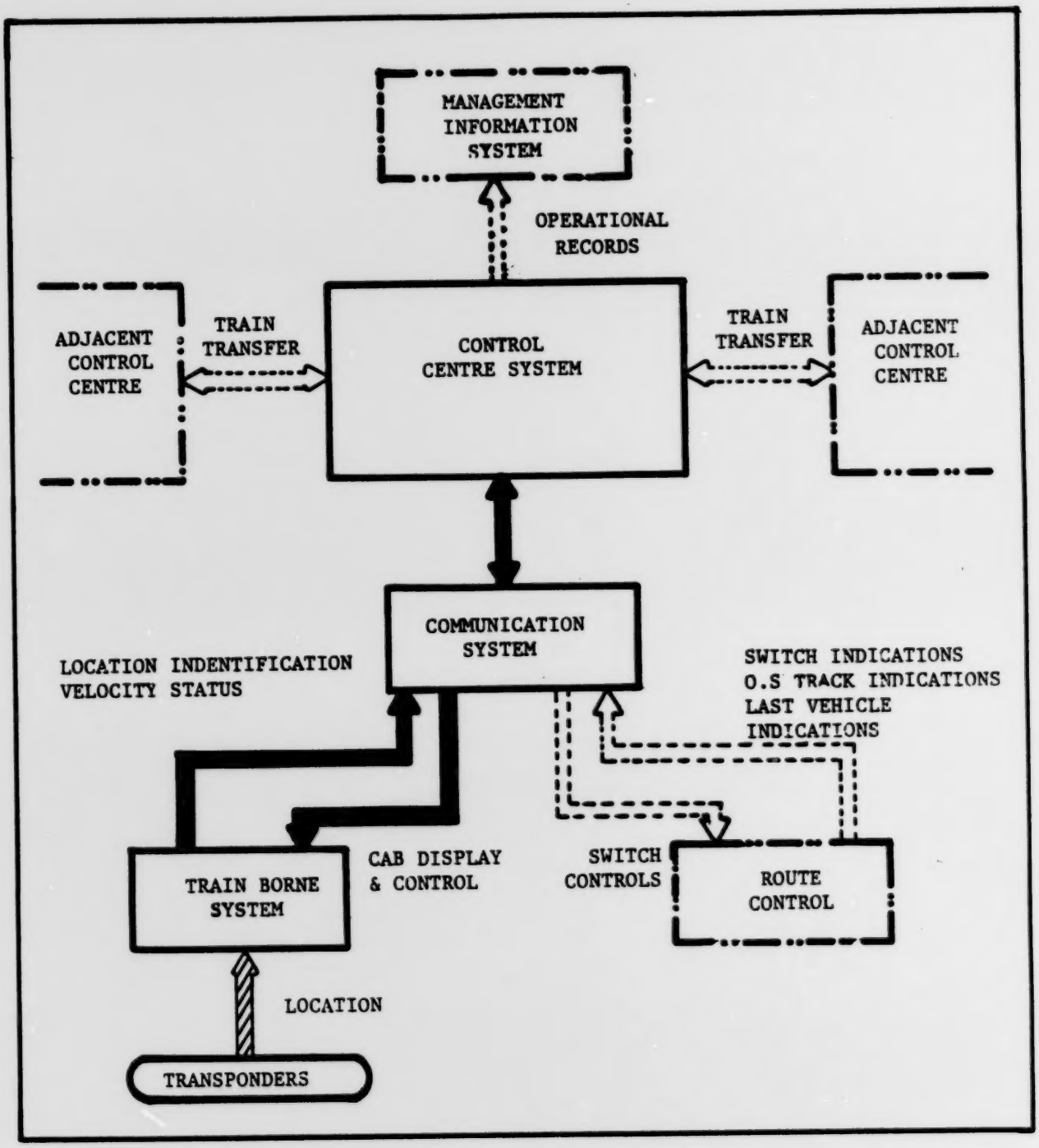


FIGURE 3 - LIC System Functional Overview

3. MAINLINE SYSTEM DEFINITION

3.1 Scope of Application for Mainline LIC

LIC is intended to increase the traffic handling capacity of train order and time table or Manual Block territory. Alternative methods of accomplishing this objective include station signalling, automatic block (ABS), and centralized traffic control (CTC), all based on the use of track circuits for train location. To attract potential customers away from the conventional and widely-accepted systems mentioned above, some specific advantages must be offered. These may include system cost, great information availability, better reliability, lower maintenance costs, and special features (particularly safety features) not otherwise available. In addition, the LIC System must offer the same or comparable capability to handle power switches, switch heaters, hot box detectors, and similar device information which is often routed into a dispatch office.

Canadian Pacific Railway has territory in eastern British Columbia where coal traffic is expected to build up significantly. Presently operating mainly under Train Order and Time Table Control, with a small amount of MBS, the Railway has perceived the need to plan for traffic beyond the capacity of that system. This is a primary opportunity for a LIC application and will be weighted heavily in considerations. The handover of train control between LIC and conventional CTC must be considered.

Canadian National Railway will carry increasingly heavy coal traffic on their Prince George to Ridley Island line in northern British Columbia, commencing in late 1983. This territory now operates on Manual Block Control and predictions are for traffic levels exceeding the capacity of that system. Canadian National is judged a less likely prospect for sale than Canadian Pacific, but consideration of their Manual Block operation will be given where possible. It should be clearly identified, however, where such consideration goes beyond the needs of the Canadian Pacific Rail train order operation.

VIA Rail have been contacted and briefed on the system. There is a high level of interest in the system but it is very unclear what VIA may wish to do or be able to do in the way of implementing LIC either as a stand-alone or as an overlay on CTC.

Furthermore, some concern has been expressed by the Senior Project Manager studying traffic management systems, that LIC does not incorporate broken rail protection. Whilst we feel that the protection afforded by track circuits is small (Reference 1),

there is at present no equivalent protection inherent in the LIC System.

For the stated reasons, the application of LIC to VIA Rail operation is at a lower priority than those of Canadian Pacific Rail and Canadian National Rail.

3.2 Development Plan for Mainline LIC

Mainline railways may be segregated from branch and secondary routes by the level of traffic handled and their requirement to meet procedural legislation set by the federal railway governing body.

The LIC System being implemented on British Columbia Railway will be suitable to handle the more limited requirements of secondary lines. However, this system will have to be expanded to increase traffic handling capacity beyond present limits. There are three main areas in which the system can be independently enhanced, as discussed below.

3.2.1 LIC Traffic Control

The AAR definition of a traffic control system is: "A block signal system under which train movements are authorized by block signals whose indications supersede the superiority of trains for both opposing and following movements on the same track."

The LIC System at present conforms with this definition, but lacks several important features which would be required for mainline operations. These features would also in part be required to meet safety requirements set by the governing body.

First, the block control between siding ends does not allow a sufficient safety zone between opposing movements. It is proposed that procedures for absolute permissive block control be adopted for mainline LIC in accordance with the following:-

- the block will be from siding to siding for opposing movements and cab-signals will not authorize movement into the block while occupied by an opposing train. For following movements, the section between sidings is divided into two or more blocks and train movements into these blocks, except for the first one, are governed by cab-signals indicating proceed at restricted speed as their most restrictive indication.

Second, any mainline system must have the capability to remotely control power switch machines and their associated equipment. On mainlines reduction of delay time is of paramount importance, and by having switches aligned by the dispatcher, the

delay at meets and passes may be significantly reduced. The system must ensure that cab display route authorities are only given when all movable switches in the route have been aligned. This will be achieved through interlocking of cab-display and power switch controls within the control computer.

The inclusion of these two enhancements would bring LIC to a level of capability equivalent to centralized traffic control (CTC) systems. It is likely that this level would thus form the base-level of a mainline LIC system. Levels below this would be unattractive compared to CTC.

3.2.2 Computer Aided Dispatching

The functions of an automated dispatch system can be categorized as primarily those of automatic or computer aided control and dispatcher information processing.

At present, the LIC system has many of the main requisites for dispatcher information processing, including such features as an automated train-sheet, dispatcher information displays and hard-copy printouts. These features reduce dispatcher workload and therefore allow more time for complex decision-making resulting in improved train control. It would be proposed that full use of dispatcher information techniques be made in a mainline system.

The system at present does not include functions for automatically controlling the issue of train movement instructions. These would be essential on very busy lines, where routine problem solving would be done by the computer, leaving the more complex problems for the dispatcher.

At this point in time it is appropriate only to define the functions that may be efficiently implemented within the LIC system. The actual development of the required software within the Host would be highly application dependent and would probably be the last step in the development of LIC.

3.2.3 Automatic Train Protection

The LIC System, being based on train-borne intelligence, is ideally suited to the incorporation of automatic train protection (ATP) functions. These functions are primarily concerned with the enforcement of train safety through forms of vigilance control to ensure movement and speed authorities are not violated.

The basic foundation for ATP functions is system capability for remote activation of train brakes. While at present the on-board computer has the capability to activate a brake relay, this

function has never been used. For mainline applications it would be attractive to use this braking function in conjunction with the following:-

- Provision in the ELU of updated speed limit based on track location. The monitoring of current speed limit against current speed would allow for a brake application in the event of overspeed.

- Prediction of braking distance based on speed and train characteristics. The braking distance could then be used to determine the safety of the train when approaching a stopping point. Unsafe operation could be avoided through an automatic brake application.

Adopting these methods would significantly improve the safety of trains operating under LIC. Furthermore, the features would provide performance in excess of most existing forms of control, such as CTC. It can be seen then that the inclusion of ATP functions would be a significant developmental step towards a mainline system. The proposal would be to select more basic ATP functions which would provide valuable experience in the field of automatic train braking. As the confidence level in LIC's ability to safely control the braking process increases, more advanced functions could be contemplated.

A full plan of evolution for the system as outlined in the previous three subsections is shown in Figure 4.

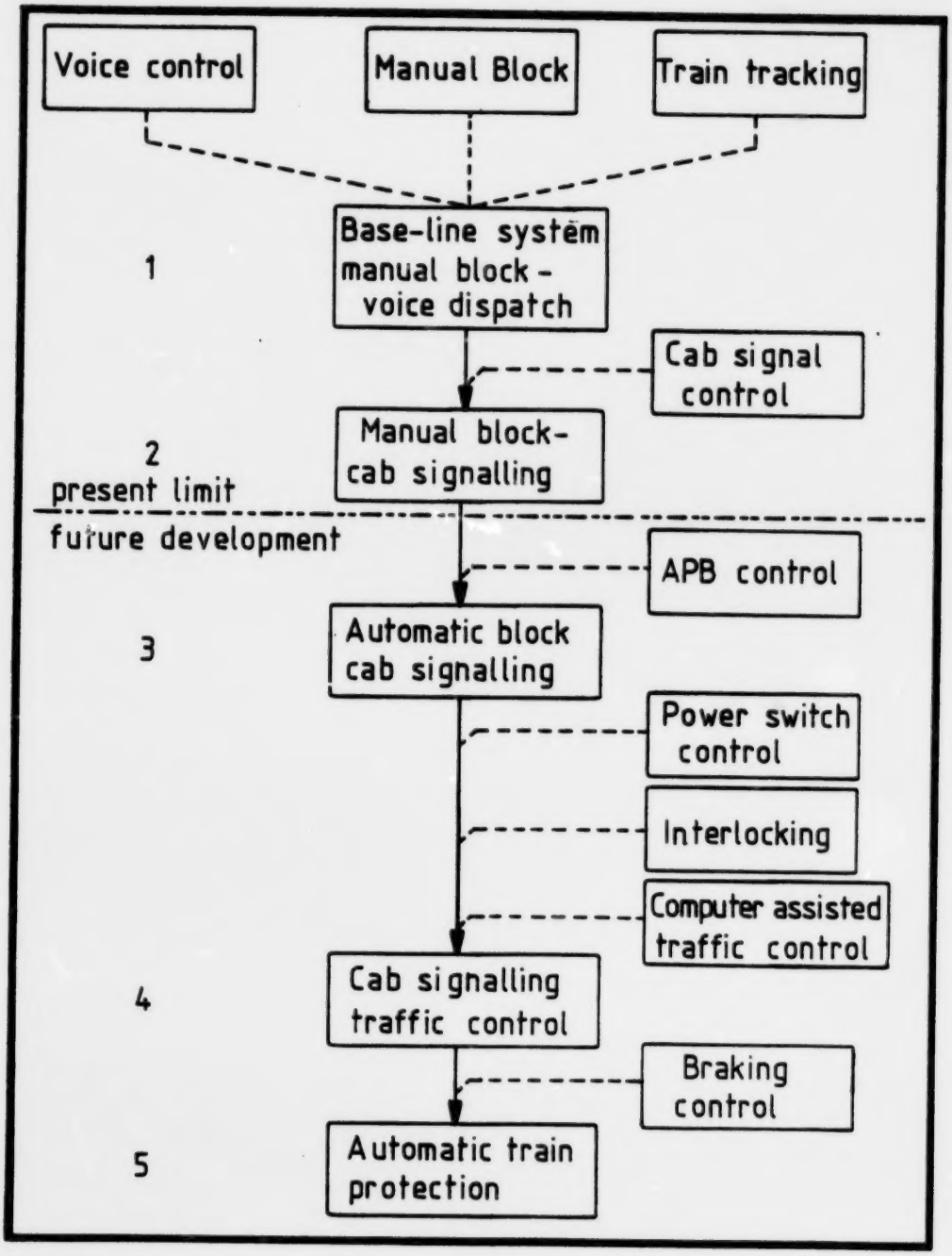


FIGURE 4 - Evolution of a Mainline Train Control System

3.3 Definition of System Concepts

In developing a LIC system for the control of trains on mainline railways, the following concepts will be adopted:-

a) The railway lines to be controlled by LIC will be of various geographical sizes and layouts; it will therefore be desirable to have the facility to alter the operation and layout, or to enlarge the size of the system.

The system shall be designed to be modular in nature such that system expansion can be easily accomplished by the use of distributed processing or bus expansion, together with modular software changes. The number of different types of module must be kept to a minimum, with each module performing a logical and well defined task in the overall system.

Modularization of a system is governed by the system architecture, and the physical and geographical constraints of the railway infrastructure and communications system. In LIC the central control system, comprising the Data Collection Processor (DCP) and the Host minicomputer, governs this modularity.

The DCP shall be modularized such that it can be expanded to handle the maximum traffic levels and number of base stations on any single mainline subdivision. The Host shall be designed to interface with several DCPs to give control of adjoining subdivisions through a single dispatcher interface.

Consideration must be given to the transfer of trains between subdivisions and also to interfacing LIC with existing control systems.

b) The system shall use direct data communications with trains through the use of point-to-train digital VHF/UHF radio and a point-to-control backbone communications trunk. The ability to achieve high speed data transfer along the entire route is required and shall be provided by selection of appropriate trunk repeaters as point-to-train communications drop sites. A high quality data path must be ensured by duplication of channels to each remote site, together with reliable and secure communications techniques.

The remote base stations shall be linked to the central control system via voice grade channels on the point-to-central communications trunk. Each voice grade channel may be divided into sub-channels depending on the configuration required.

The system shall be capable of interfacing with voice grade facilities over any of the following transmission media:-

- Microwave radio (common carrier, light route, dedicated etc.)
- VHF/UHF point-to-point radio.
- Leased/private telecommunications lines.
- Open wire lines.
- Optical fibre line systems.

c) Precise tracking of trains throughout a controlled area shall be achieved by independent coarse and fine tracking techniques.

   a) Coarse fixed block tracking shall be by interrogation of passive wayside DIGITRAC transponders programmed with a unique position identifying code. Train borne interrogators shall search for transponders and upon detection, receive many frames of data containing the location code. The on-board reader must average data frames, range check the code and validate error detection codes to provide highly secure transfer.

   b) Independent fine tracking between location transponders shall be achieved by an odometer which measures the distance travelled to an accuracy of better than 0.05 miles. Automatic calibration shall ensure that wheel wear, wheel slip and other incremental errors do not affect odometer accuracy.

d) Cab signalling shall afford the engineman "electronic vision" which together with location readout will enable safe deceleration on the approach to restrictions on stopping points. Plain language block authorities shall be displayed for the current and next two blocks ahead, together with route, speed limit, actual location and speed. An interactive directive display field shall allow for engineman to dispatcher interfacing under specific operating conditions. The security of displayed block authorities shall be achieved by logically redundant data paths utilizing an enable-confirm-execute routine. Further security shall be afforded by cognitive diversity in giving numeric/abbreviated instructions in addition to spelled out instructions.

e) Normal LIC operation shall require each train to be equipped with an Engine Logic Unit (ELU) at both the head-end and caboose for the purpose of transponder reporting. This shall give the capability for the central control system to safely determine the extent of track occupancy of a train.

   However, railroads are turning toward ending the use of the caboose and tail-end crew. It is proposed that under these circumstances, the GLENAYRE DIGITAIR system for monitoring train integrity and rear of train brake pipe pressure be used. The DIGITAIR system (see Appendix E) shall be interfaced with LIC such that train movement can be prevented until brake pipe continuity is achieved and a safe brake pressure obtained up to and including the last car.

To overcome the problems of fail-safe clearing of blocks without LIC caboose equipment, a last vehicle detection system shall be employed. In this system, a sending element shall be affixed to the train's last car which shall actuate a receiving element at the end of a block section. The system shall ensure that the sending device may only be attached to the end of a train (ie. never inside a composition of vehicles). Precautions shall be taken to ensure that if the sending device is at the front of a train (either due to a mistake or running in reverse), it should not cause clearing of a block.

f) Power switch control concepts should be incorporated into the LIC system and a wayside radio switch control unit should be specified. This unit should be based on existing engine logic unit hardware in the interests of standardization.

Standard railroad practices shall be employed to ensure the safe operation of power switch machines. Particular attention shall be paid to ensuring that inopportune movements of the switch are not made when it is occupied by a train.

g) Automatic train protection functions shall ensure that engineman vigilance is maintained in conforming with movement commands and fixed roadway speed limits. The system should operate on the automatic braking after warning principle whereby for required deceleration, brakes are actuated automatically if the engineman does not respond to an audible warning. Specific attention shall be paid to overcome weaknesses of conventional systems in providing feedback of engineman actions.

h) Fail-safe operation shall ensure that failure of a vital system does not cause the system to be less safe than it was before failure. The central control system shall use diversity between the Host and DCP to compare vital control commands. As previously described, logically redundant data paths shall secure the train display of movement commands. Extensive use shall be made of error detecting codes and highly structured protocols to provide secure data transfers.

i) Automated dispatch techniques shall utilize LIC's highly detailed and precise train performance and operations data base to provide a real-time solution to optimum train scheduling. Full use shall be made of CRT colour graphics and hard copy terminals to give the dispatcher a complete overview of system status and to assist with routine clerical duties.

j) The central control system shall incorporate manual procedures based on the manual block system for the dispatching of non-LIC equipped trains in LIC territory. These procedures shall allow for authorities of movement by written authority verbally transmitted, computer protection of these authorities, and manual OS procedures for tracking trains.

k) The system shall be designed for high reliability, availability, and maintainability. Consideration shall be given to forms of ensuring availability by duplication of hardware at the central office.

l) The implementation of the system shall be possible in logical steps as warranted by expansion in traffic levels and the railway's capital expenditure requirements.

m) In consideration of operating practices for modern passenger trains, such as the light rapid and comfortable (LRC) train, the system shall be designed to operate at speeds of up to 200 Km/h.

n) The LIC system design shall use proven railroad control concepts to provide for the safe movement of mixed types of train in conditions of high traffic density and increasing speed. However, equipment failures will arise and the dispatcher may be stripped of the protection provided by the system. Under such conditions, protection should be provided for by a set of LIC operating rules.

4. FUNCTIONAL EXTENSIONS TO LIC

4.1 Remote Activation of Train Brakes

This function would allow for the transmission of a command to the lead-unit ELU of a train which would subsequently cause some form of train brake application. It could be envisaged that this command could be initiated by two independent actions:-

a) Manually through a dispatcher entered command upon perception of an impending collision or dangerous situation.

b) Automatically by the Central Computer System when it has determined that a train will or has illegally entered a block of track or is in overspeed of the limit.

The command would be transferred from the DCP to the specified ELU in the same way that control point authorities are handled.

Insofar as the locomotive equipment is concerned, some means of influencing the train's air-brake system must be effected. Considering the type of control gear used on the braking system, it would be necessary for the ELU to activate the brakes through relay contacts. The provision of one addressable relay would provide a basic brake application capability. However, more than one form of brake application may be considered depending on the level of danger implied:-

- Application of the train Emergency brakes would vent the brake pipe quickly through a large opening to atmosphere and the equalizing reservoir vents to atmosphere at normal rate. Emergency brake applications must, however, only be used in cases where it is necessary to obtain the shortest possible stop. Incorrectly applied, unnecessary damage may occur to wheels, track, traction motors or lading.

  It would only seem diligent as far as LIC is concerned to allow remote emergency braking as an absolute last measure. Furthermore, initiation should be under the control of the dispatcher as outlined in a) above. In this way, the dispatcher can assess the level of hazard and act accordingly. If initiation were under the control of the system, a fault could conceivably occur which would cause an application which in itself would cause extreme hazard to the train.

- Application of train braking through an independent penalty brake application affected via the locomotive P-2-A brake valve. Such an application will be suppressed if the engineman has already effected a brake application with the brake cylinder pressure 25 psi or more. Once a penalty

brake application has occurred, the P-2-A brake valve remains in the applied position until the automatic brake valve handle is placed in the suppression position and the P-2-A valve reset.

This form of application is used in vigilance and deadman's control where unless a pedal is held down or operated at specific intervals, the P-2-A valve is operated causing a penalty brake application. In addition, Automatic Train Stop (ATS) and Automatic Train Control (ATC) systems also use the P-2-A valve to apply penalty braking as a tie-in with wayside signalling. Obviously this mode of operation would closely parallel that sought for the LIC system when providing system controlled automatic braking as outlined in b) previously.

The 25 psi brake pipe reduction provided during penalty braking is equivalent to a full service application and will result in a full train stop under most conditions. However, it would be advantageous to pre-empt the application by an audible warning to allow the engineman to make a service application and suppress operation of the P-2-A valve.

In actual fact, as part of the prototype development phase, the ELU has already been provided with a reed relay output providing two single pole contacts. However, connections to these contacts are not at present brought out to an external connector. It is envisaged that the work required to do so would be fairly minor although with only a single relay a choice would have to be made between emergency and penalty braking.

Insofar as the DCP is concerned there would have to be provision for generation of the braking command message(s). The control for this will be software generated and it is not envisaged that any hardware extensions will have to be made.

It is recommended that further investigation be carried out concerning remote braking methods specifically in respect to the merits of emergency and penalty braking under different circumstances.

4.2 Communication of Speed Limit to ELU

The display of speed-limits to the engineman is a function which has already been incorporated in the experimental LIC trial system. Testing of this system revealed certain difficulties with the concept of updating the limit in a fail-safe manner. However, the trial system was based on the moving-block principle, where the speed limit shown acts as an authority and target speed. Obviously in such a system, a problem could occur

if the speed-limit is not taken away when a train is approaching a stopping point.

With the fixed-block principle now adopted for LIC, the provision of a speed-limit display should be perfectly feasible. Here the speed limits given will be for information only and control point authorities will still govern movements within the defined blocks. In order for the limit to be updated according to location, it would be necessary to store in table form the speed limits for the various types of train to be controlled. The table could be stored either in the central computer or in the ELU itself. Storage in the ELU would be attractive from the point of view that the speed-limit data would not then have to be transmitted between central and the train, a method which would further load the communications system. Despite this it would not really be practical to store such a large volume of data within the ELU. Furthermore, amendment of the speed limit tables would create logistical problems with many ELU distributed in the field. In view of this it would be most practical to store the speed limit table in the DCP and Host and to communicate limits to trains together with respective block authorities.

The table could be formed in one of two different ways:

a) by Mileage - the table containing the mileage at which the speed limits change and the associated speed-limits for different types of trains, e.g. passenger or freight,

b) by Transponder Number - the table would become integral with the existing track model, transponders would be placed to coincide with the speed limit changes.

The speed-limit data could be transmitted to the relevant ELU through the provision of a new message transaction in the DCP-ELU protocol. The process of updating the speed limit would have to be handled in two different ways depending on the train's direction of travel over the limit change.

- If the speed limit is to be lowered in the train's next speed limit change, then the mileage at which the train should start to slow down should be calculated. The train's odometer could then be checked against the calculated mileage, and upon reaching this mileage the speed limit could be updated. This early display of the change would allow reaction time for the train to be slowed and to actually enter the new speed zone at the safe speed.

However, the problem of actually calculating the distance to slow down the new speed would be quite complex. Probably the best method here would be to have a fixed table of stopping distance versus initial velocity from which the distance to slow from one speed to another could easily be computed. This table could either be stored in ROM within the DCP, or alternatively down loaded from the Host on system initialization.

- If the speed limit is to be raised in the train's next speed limit change, then the new speed limit should be displayed only after the lead unit has crossed the transponder at the actual limit change or has reached its defined mileage. However a rule would have to be enforced stating that the train must proceed for its length after receiving the increased speed limit before the speed is increased to the limit set. In this way it can be ensured that the whole train has cleared the lower speed limit before the speed is increased.

The methods described fit in fairly easily with the existing LIC concepts and hardware, but do so possibly at some expense to efficiency. A less cumbersome method of providing the engineman with speed limit information could be envisaged, in which two limits were displayed: the current limit and the next limit ahead. The two limits could be displayed in separate fields on the cab-display and the mileage which the next limit comes into effect also displayed. The next speed limit would be displayed only if its location was within the confines of the train's existing authority, it should be stated that in either of the methods described the speed limt would be for information and would not be taken as authority for movement.

The use of this method would be attractive by virtue of the advanced notice the engineman is given of impending changes, thereby allowing better brake system air management. Also the control routines would be greatly simplified over the method using a stopping/slowing distance algorithm. There would be some implication on the cab-display format, which would probably have to be completely revised to allow suitable space for the new information.

4.3 Overspeed Detection and Brake Application

The incorporation of this function would be a logical extension to provision of an in-cab display of speed limits and could also make use of the remote brake actuation facility. Given that the previous two functions had been implemented this function would be solely software controlled and would not require any special hardare. There are two ways in which this software could be practically implemented:

a) The overspeed checking software would be located in the DCP and would rely on speed data solicited from trains during the regular polling cycle. However, the status message from the train does not contain the current speed limit. The DCP would have to acquire this from the look-up speed limit table described in the previous section, using the mileage provided from the status message. Once the speed and speed-limit have been ascertained the software can check for overspeed and if detected take one of several actions:

- cause an alarm to the dispatcher and allow him to take manual corrective action based on his assessment of the situation. Note, he could make use of the manual emergency brake activation described in section 4.1 if there was a great enough hazard.

- generate an alarm in the locomotive cab of the train, the alarm to remain activated until the engineman lowered the train's speed to the current limit.

- generate a warning alarm to the engineman for a preset period and if braking action is not taken automatically apply a penalty brake application.

Of these actions, only the first may be considered as really practical, as the control loop between the DCP and ELU for the other two would be impractically long. In addition, the speed as obtained by polling would only be determined at infrequent intervals. If these latter two actions are desirable then the second way of implementing the software as described next should be used.

b) The overspeed checking software would be located in the ELU and could continuously monitor the train's speed against the current limit on the cab-display. In practice the function could be handled by the use of a specific timer upon whose expiry a subroutine could be called to check the speed and limit and reset the timer. Once an overspeed is detected an audible alarm could be sounded, informing the engineman of his violation. At this point another timer could be started to allow the engineman to react. If upon expiry of this period the overspeed still exists then the remote brake application relay can be set. Alternately instead of checking at the end of the period for overspeed, a check could be made to see if the train brakes had been applied. This would require some form of status bit from the train braking system to show when the automatic brake valve handle had been moved to the service reduction position.

In either case the operation of the relay would set the P-2-A valve and cause full service reduction until suppressed by the engineman. The P-2-A valve would be reset by software only when the train's speed had dropped to the current limit.

This second method has the following advantages over the method previously described in a):

- the software is incorporated completely within the ELU, thus eliminating any need to communicate with the central computersystem. This would be conducive to the speed, safety and reliability needed when an automatic brake application is made to prevent an unsafe condition.

- the procedure for checking the speed would be simpler since no table look-up is required. Also the checking would not require message transactions between the ELU and DCP which are subject to delay.

- it would require no change to existing DCP/ELU protocols since there is no one need for a new command as in the first method. This means that it would not add to the loading on the communications system.

- the only hardware additions required would be a memory expansion within the ELU to accommodate the new software tasks.

4.4 Prediction of Braking Distance

The ability to predict rail vehicle braking performance has been an area of vital interest to railroads. The expansion and technological improvements in freight, passenger, and rapid transit operations have intensified the need for more accurate and efficient methods of predicting performance.

There are numerous factors which affect the braking performance of a train which may be summarized as follows:

a) Locomotives
   - weight
   - number of units in train

b) Cars
   - weight
   - number of cars in train
   - length

c) Brake equipment type
   - control valves
   - rigging

d) Brake shoe
   - high friction
   - low friction

e) Brake cylinder pressure

f) Brake shoe pressure

g) Wheel temperature

h) Rigging efficiency

i) Dynamic brake

j) Train resistance

k) Grade

Factors a) to d) remain constant during a brake application and can be readily determined. The other factors, which vary during a brake application, must be thoroughly analyzed in order to be mathematically defined. The effects of these factors are discussed in Reference 2.

The paper discusses each of the factors individually and how they affect overall braking. Empirical formulae are defined for each factor and on overall braking distance algorithm is thus derived. A computer program simulating the braking mechanism of single vehicles and consists or trains of vehicles was designed. Testing of this program showed that the algorithm could very accurately predict the braking distance, given the train's initial velocity. The comparison of computed figures with data from an actual train under the same conditions showed that braking distance errors were within 5%.

It may be concluded from this and other similar papers that practical prediction of braking distance to a reasonable level of accuracy can be achieved. However, prediction under the controlled conditions given in the paper is vastly different to the same thing on board a real train. It can be expected that many factors used in computation will be dynamically changing. While the computer program would have the flexibility to accomodate infinite variations of conditions, it is not always possible to know all specific conditions for any particular train. In many cases educated assumptions must be made. The limiting factor is that the computer would only accurately simulate braking under the conditions prescribed to it, but it has no way of determining whether or not these conditions actually exist on the train. The computer program previously mentioned required the input of twenty-five different factors, many of which have a significant level of uncertainty. The presence of faulty brake equipment or a pinched brake line could easily render the input information vastly inaccurate. If the predicted braking distance were used, for example, to stop short of a train ahead, the computer may advise a stopping distance shorter than that actually achievable with the train. Obviously under such conditions there would be a serious lapse in the safety of operation.

One method for incorporating the prediction program into the ELU would be to use a simplified algorithm which would take into account only the main factors, such as:

- initial speed
- tonnage
- car equipment
- grade profiles

The remaining factors could be accounted for with a constant which would take into account the worst case figures for each separate factor. In this way the ELU could make an estimate as to the maximum required stopping distance. Obviously the ELU would have to be provided with some form of tonnage and equipment input, either directly from the engineman or downloaded from central at the start of a trip. Also central would have to provide the ELU with the required grade profiles.

A more practical approach would be to use a fixed curve of speed versus braking distance held in ROM in the ELU itself. The curve would be selected to provide at specified speeds the maximum possible stopping distance. Obviously this method has some serious drawbacks in that if the worst case stop, e.g. on a gradient, is used as the basis for the curve, then under less severe conditions the computed distance may in fact be twice that actually required to stop. However, at least the error is 'right-side' and would ensure the train has stopped well short of a potential hazard. All things considered this would seem to be the most suitable method of computing braking distance within the ELU. It would offer the following advantages over a more complex and accurate algorithm based method:

- All of the computation can be done within the ELU, and there would be no requirement for central to ELU communications. This ensures that the communication system is not further loaded.

- The fixed braking curves would be similar to those used in conventional signalling calculation and could draw on their experience.

- The simplicity of the braking curve look-up table would not impose a high loading on the ELU's central processor.

- Holding the braking curve look-up in ROM within the ELU will mean that the system will be self initializing.

4.5 Use of Braking Distance To Ensure Safety

The previous section discussed the calculation of a train's braking distance given its initial velocity and operating parameters. In this section it will be assumed that the ELU is capable of determining the stopping distance for any given initial velocity.

The computed braking distance can be most efficiently used as the basis for an automatic warning system (AWS) which would ensure engineman vigilance when approaching a stopping point. The basic concept of AWS is to warn the engineman that he must apply the brakes in order to stop in obedience to operating authorities. Usually systems function on the braking after warning principle whereby an audible/visual warning is given followed by a period in which to apply the brakes. If at the end of this period no action has been taken then AWS would enforce an automatic penalty brake application as outlined in section 4.1.

In LIC, AWS could be a logical extension to the previously discussed concepts of braking distance prediction, speed monitoring and automatic braking. However, at present LIC does not give the engineman the exact location of a stopping point. Once the last authority on the cab-display has rolled-up, the onus is on the engineman to apply the brakes according to his knowledge of the next control point's position. It would seem logical to give the engineman a directive on the cab display in the form "DO NOT PASS CPXXXX", thus giving the exact location of the stopping point. The system now knowing where a stop is to be made can use the predicted braking distance to compute the braking point.

An AWS system could be implemented entirely within the ELU and would function in the following manner:

a) The last control point authority rolls up and there are no further authorities displayed. The system realizing this displays the "DO NOT PASS" CPXXXX directive, notifying the engineman of a stop at mileage XXXX.

b) The current odometer value is subtracted from the control point mileage of the "DO NOT PASS" instruction, to determine the remaining distance to be travelled. As control point numbering is in decimiles it is a fairly simple process to deduct the odometer value in decimiles.

c) Having calculated the remaining distance i.e. the available braking distance, the ELU obtains the current braking distance from the braking profile held in its memory. This distance will be dependent upon the train's present speed, which is used to reference the braking profile look-up table. The train brakes cannot be instantly applied by the engineman though, and therefore a reaction time must be allowed for. This time can be related to distance at a particular speed and can be added to the braking distance to give an overall braking distance.

d) The ELU would periodically check the available braking distance against the overall stopping distance. For this purpose a specific timer would be set within the ELU and upon time-out the check would be performed and the timer reset. When the available and overall braking distances are equal, the engineman would be alerted with an audible and visual AWS alarm. At this point the ELU would initiate a reaction-time timer to allow the engineman to commence train braking. Normally upon receiving the alarm the engineman would make a service brake application, increasing brake pipe reduction to the suppression level (23 - 26 psi). This action will check the progress of the train and commence deceleration.

e) The reaction time is sufficient for the required brake pipe reduction to be applied under normal circumstances. When the timer expires the ELU would for a preset duration activate the relay controlling the locomotives P-2-A brake valve. Under the normal conditions with the automatic brake valve in suppression position the action of the P-2-A brake valve is held suppressed. However, if for some reason the engineman has not been able to apply the brakes the P-2-A brake valve would activate and apply a penalty application. This would ensure safety by bringing the train to a full stop under most conditions. A point of note is that when the ELU relay has momentarily operated, the AWS alarms could be removed. This would then notify the engineman that he could adjust the braking of the train without invoking a penalty aplication. This would be particularly useful where it is desired to reduce the air-braking and apply the dynamic brakes.

f) As a further option to the basic AWS system described, a braking-profile overspeed function could be incorporated. It would be a requisite here that the cab-display be capable of displaying speed limits as described in Section 2.

Once the ELU had given the AWS warning and the reaction timer had timed out, the train would be at its initial point on the braking profile. The ELU could then sample the profile look-up table at say ten second intervals and from the distance travelled determine the safe maximum speed. This speed would be used to update the cab-display current speed-limit region.

If desired overspeed control as described in section 3 could then be applied to ensure actual train braking does not exceed the bounds of the safe profile.

The system described is flexible in that a certain subset of functions may be implemented on a stand-alone basis. As a first step the implementation of the "DO NOT PASS" directive would be necessary and would at least give the engineman a permanent reminder of the limit of safe travel. This could be enhanced further by the addition of braking point AWS warning and automatic penalty brake applications.

The final enhancement of braking profile guidance would afford the train with the utmost safety while also allowing the engineman a degree of flexibility.

It should be noted that the development of such an AWS function in the ELU would be a significant task, and would probably require an extended period to perfect. It may then be more appropriate at this point in time to merely consider the "DO NOT PASS" function together with an optional readout on the cab-display of the available braking distance. This method would leave braking totally in the hands of the engineman and it would be his duty to ensure he does not overrun his authority.

4.6 Unauthorized Block Violation

If the "DO NOT PASS" method were solely adopted as recommended above, it could be expected that stopping overruns would occur. Under these circumstances it would be important to at least warn the engineman of his "ILLEGAL ENTRY" and better still to automatically apply the emergency brakes.

Such an illegal entry function is not new in the LIC system, as it was incorporated in the moving block experimental system. However, with the adoption of a fixed block system the requirements are somewhat changed. The following outlines the requirements:

a) Detection of an illegal entry: Entry violation will be declared by the ELU whenever a lead unit of a train crosses a transponder that it has no cab display authority to cross.

b) Alerting the engineman of an illegal violation: An "ILLEGAL ENTRY" directive would be displayed, accompanied by an audible alarm. The alarm must be acknowledged by the engineman.

c) Transmission of illegal entry information to central: The transmission should be handled within the framework of existing DCP-ELU messages. The DCP must pass the violation information on to the Host.

d) Alerting the dispatcher of an illegal entry: The receipt of an illegal entry message at the Host should cause

- a log on the significants event printer
- a unique symbol on the graphics track diagram display to show the CP violated
- a change in status of the train ID display on the graphics track diagram display to show the train in violation
- logs on the significant events printer for illegal entry display and acknowledgement by the engineman.

e) Acknowledgement and cancellation of illegal entry by dispatcher: It will be necessary for the dispatcher to acknowledge the illegal entry alarm and thereby cancel the ILLEGAL ENTRY display.

f) Disabling the illegal entry function: At certain times such as when dispatching trains under written authority, it may be advantageous for the dispatcher to disable the illegal entry function. Caution must be exercised here as it is a safety function and, if inadvertently left disabled, could lead to a serious hazard.

The basic illegal entry function as described would seem to be logical as an initial extension to the basic LIC system. It would be highly desirable in that it would clear the way for incorporation of remote brake applications.

Considering the operation of the violation function, it could be attractive to apply the train's emergency brakes if the engineman does not immediately acknowledge the "ILLEGAL ENTRY" alarm. Although this may seem to be an excessive action, the conditions under which such a violation could occur must be considered. If two trains are to meet at a siding equipped with hand throw switches, then the consequence of even a short overrun could be a head-on collision. However, the function would only provide a limited degree of protection, as once a violation occurs it may be too late to avert a collision. One must seriously consider the fact that the LIC control point signs are only 50 ft. apart, this being the only safety zone between two trains under many circumstances. Could the application of emergency braking achieve anything in such a short distance? Realistically, the answer must be 'no'.

The illegal entry function would provide a limited degree of protection, especially when meeting or following trains have not closed up significantly below emergency braking distance. It would be highly attractive at this time to implement such a function as the first step towards automatic train protection in LIC. Furthermore if used in conjunction with the DO NOT PASS function described in section 5, the level of protection could be further enhanced.

4.7 Remote Control of Switch Points

In the eyes of most mainline railways, the inclusion of power switch control in a traffic management system is seen as a necessity. It would, therefore, seem important to develop methods to provide such a feature within the LIC system. However, there are some inherent problems concerned with providing power switch control such as:

- the power switch machines would require the provision of a power source at each wayside location. At present LIC has advantages in that no wayside power is required.

- to provide locking of the movable points during the passage of a train, a track circuit would have to be provided at the switch. There is something of a problem conceptually in providing track circuits in the LIC system.

- a wayside housing would have to be provided at each location to contain switch machine and track circuit ancilliary equipment as well as LIC communications equipment.

- the equipment previously described at each switch location would require a considerable amount of installation effort and expertise. At present Glenayre does not have the expertise and may not have the resources to provide the level of effort required. The fact that the power switch machine, relays, housing etc. would have to be purchased from an established signalling company may make it attractive to sub-contract the complete work package.

- the inclusion of power switch control and indicator messages in the communications protocol would significantly add to the loading on communications throughput.

Insofar as the system is concerned, a totally new hardware element would have to be introduced to interface between the power switch equipment and the LIC communication system. This unit termed a radio switch controller unit (RSCU) would functionally be very similar to the train-mounted engine logic unit. The development of this unit was considered significant enough even at this early stage to warrant preparation of a full functional description and specification (Appendix F). This document defines the operation of an RSCU suitable for providing a fully integrated switch control capability within LIC.

The implications on the DCP of incorporating such a capability are discussed under two categories:

4.7.1 Interaction with the Host -

The DCP should be capable of:
a) Receiving Data Update messages containing RSCU ID's
b) Receiving Commands for alignment of switches
c) Sending power switch status data to the Host upon request

These capabilities will be individually discussed.

a) Data Updates

At system power-up, the DCP is loaded with various static data from the Host. A new message should be added to the Host/DCP Protocol to allow the down-loading of switch controller ID's. The message could be one block long (13 bytes) and contain up to five RSCU ID's (16 bits each). The last byte of the message would be the BCH code.

The DCP response to an RSCU Data Update message will be an acknowledge message. The RSCU ID list will require an increase in ROM/RAM storage within the DCP.

b) Commands

At any time during system operation, the DCP may receive commands from the Host pertaining to power switch control. The Host Communications task should allow the receipt of four new commands:

i) Normal Throw: Command to throw the switch to normal position (i.e. aligned to main)

ii) Reverse Throw: Command to throw the switch to reverse position (i.e. aligned to siding)

iii) Normal Override: Command to throw the switch to normal position, in spite of it being out of correspondence or having failed.

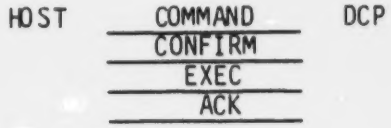
iv) Reverse Override: Command to throw the switch to reverse position, in spite of it being out of correspondence or having failed.

Each of these commands will have a different message code. It would also contain the 16-bit ID of the RSCU that controls the switch in mind.

There are two ways in which this transaction would be handled ensuring data security.

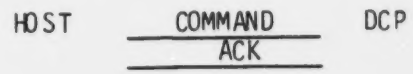
One is to provide a double hand-shake such as exists in command transactions between the DCP and the ELU. This requires a Confirm message from the DCP in response to the command. The Confirm message would be an echo of the command itself. The Host, upon receipt of a correct echo, would then send an Execute message. The transaction will be terminated when the Host receives an acknowledge message from the DCP indicating the receipt of the Execute.

The double hand-shake takes on the form below:



The above procedure provides a very secure data communication in which the chances of executing erroneous commands (e.g. throwing the wrong switch) are greatly minimized.

Another way to handle RSCU command transactions between the Host and the DCP is a simple Command/Acknowledge routine just as all Host/DCP Command transactions are implemented. This simple hand-shake is shown below:



This procedure relies entirely on the BCH code checking and the inherent security of the Host/DCP data link which has proven to be sufficiently safe.

c) Data Requests

At intervals during system operation the DCP will receive requests from the Host for significant data collected from the field. One of the reports produced by the DCP in response to Data Request messages is the Switch Status Report. Every time there is a change of status in a switch, a Switch Status change will be queued for reporting to the Host. This requires the addition of another circular list to the Priority Data queues. It also means that a new message should be added to the Host/DCP Protocol.

4.7.2 Interaction with the RSCU's

The DCP communication with RSCU's fulfills two functions:

a) Switch Status Data Collection and
b) Switch control

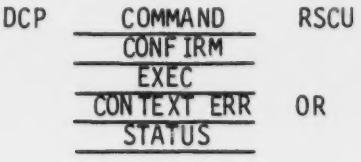
a) Switch Status Data Collection

The DCP should poll RSCU's on a periodical basis gathering power switch status data. The polling protocol requires the following message transaction:

The DCP global data should hold a record for each RSCU accessed by the 16-bit switch ID and containing the status data for the power switch. Every time a Status message is received from a RSCU, the status data would be checked against the old status bits in the RSCU record. If a change has occurred since the last poll, a Switch Status Report will be queued up to be sent to the Host upon its request.

b) Switch Control

Once the Host/DCP transaction for a switch control command is successfully completed the DCP is ready to communicate the command to the associated RSCU. The protocol will consist of a double hand-shake to ensure data security over the radio link. The transaction will contain the following messages:



The message structure would be adopted from the DCP/ELU Protocol. This structure is characterized by 4-byte blocks, (31, 26) BCH code, one odd parity bit per block, and HEAD and END bits for each message.

In concluding this section on remote switch control, several important factors must be considered. First, could the DCP handle the additional loading imposed by having to regularly poll RSCU's and issue movement commands? It may be necessary to adopt a multiple processor DCP with a dedicated CPU for handling RSCU's. Second, the use of intelligent devices on the wayside must be questioned in respect to LIC's train-borne intelligence concept. In addition the RSCU would have a track circuit and it would therefore possess the major requisites of a wayside based signalling system. This brings one's attention to a complete inversion of the present LIC system with the ELU's (or RSCU's) on the wayside and transponders mounted on the trains. Obviously this kind of negative thinking is not constructive to LIC, but is a natural result of the analysis of RSCU potential. Finally the adoption of power-switch control will undoubtedly carry a very high cost penalty. The LIC system has always been regarded favourably because of its low cost per mile compared with CTC. However, including power switch control may dramatically reduce the cost differential between the two systems.

At this point in time it would not be recommended that switch control features be implemented in the LIC system. However it must be ensured that the DCP and other system modules have additional capacity to easily incorporate these functions at a later date. It would seem more appropriate to develop the required hardware when a specific mainline application has been finalized.

5. DATA COLLECTION PROCESSOR DEVELOPMENT

5.1 Design Motivation

The Data Collection Processor (DCP) is responsible for collecting and maintaining a database for each field unit, which it does by sequential polling of the units on a continuous basis.

The LIC prototype development phase saw the realization of preliminary hardware and software for a base-line DCP. This DCP performed the following functions:

a) Polled each engine logic unit (ELU) in sequence and obtained identification, transponder crossing reports, and status information.

b) Determined train location from transponder crossing reports

c) Handled system communications, selecting remote communications site according to train location

d) Monitored engine odometer accuracy

e) Brought under LIC control any ELU which entered LIC territory or transmitted a speak-up.

f) Precisely tracked train movements and provided a hard copy display of train location versus time.

This preliminary DCP was used during the basic tracking tests in Nov. 1981 together with the pre-production prototype engine logic unit. The performance of the DCP during these tests brought to light some serious flaws in the basic design. Specifically the following problems were encountered:

- Frequent processor hang-ups due to the physical layout at the microprocessor and multiplexor boards. The problems were traced to noise prone circuitry and cross-talk on some clock and control lines which caused spurious voltage pulses.

- The main data and address structure was not able to support an increase in system processing power. It was discovered that the DCP was seriously overloaded and that the higher speed and memory requirements needed could not be provided due to excessive bus-loading and contention.

- The mechanical design proved to be impossible to service during development and test work. The non-modular packaging concept required complete disassembly to trouble-shoot fairly minor problems. Assembly time was long and difficult and could be significantly reduced with alternative design methods.

As a result of these problems and in anticipation of expansion in the DCP's capability to handle more advanced functions for mainline railroads, it was decided to initiate a redesign. The new DCP was to be designed such that the central control system could be customized to a particular set of application specific features.

Collection and maintenance of a database from the field equipment is a foundation upon which the high-level command and control functions are based. The addition of a limited display capability to this foundation may fulfill the requirements for a base-line MBS tracking system as defined in part 3. Hence a system comprising field equipment, a communications subsystem, and data collection processor is logical as a system to meet the requirements of modest or secondary lines.

For more ambitious applications, a separate command and control Host processor sized to handle the required degree of complexity can operate on data received from the DCP. In addition, the DCP will have to be expanded to provide the increased data required for more complex operations.

The following design features were considered desirable for the next generation DCP:

- Use of the powerful Z-80 microprocessor to take advantage of experience gained with the previous design
- Identical device addresses with the old DCP
- Compatibility with a high level language such as Pascal
- Highly modular and expandable architecture and packaging
- User defined mix of ROM and RAM
- Expandable serial input/output parts
- Use of existing technology and off the shelf components
- Minimal use of random logic in favour of LSI
- Rugged design

5.2 Design Concepts

A design study was carried out to define the practical methods of implementing a new DCP design. With the requirement that two DCP's would be needed in mid-82 for the BCR operational LIC system particular attention was paid to solutions which could be quickly realized.

The following sub-sections discuss the four design solutions that were identified as meeting the requirements of a DCP.

5.2.1 Redesign of Existing DCP

This approach required that the existing DCP hardware be reworked to solve the problems previously identified. This would require effort in the following areas:

a) Mechanical layout and packaging
b) Physical layout
c) Circuit board interconnect scheme
d) Processor, I/O multiplexer and memory expansion board electronics

It can be seen that this solution would have a maximum impact on hardware design requirements while the corresponding requirements for the software would be minimal. Furthermore it could be expected that the new design may suffer from the same lack of expandability and flexibility on the existing DCP. Another problem was evident in the limitations of available memory chips which would impose serious restrictions in the design. It is likely that to overcome these problems the new design would have to deviate significantly from the existing DCP concept.

The potential for this solution to meet the requirements for a mainline DCP seem slight in view of the inherent design limitations.

5.2.2 Minicomputer and Specialized Interface

The use of an off the shelf minicomputer such as the DEC PDP11/05 was an attractive solution, although significant work was involved in designing specialized hardware. This design would lead to effort in the following areas:

a) software concepts, design and implementation
b) specialized I/O and timing hardware
c) packaging

Obviously this approach would deviate from the specified requirements in that the Z-80 microprocessor would not be used, thereby imposing maximum impact on system software. However, the fact that the minicomputer could be obtained quickly off the shelf would allow software development to commence independently of any hardware development work.

The hardware development effort required to design a communications interface for the minicomputer was fairly moderate and there was a low risk of hardware stumbling blocks. It was a definite advantage that Glenayre had only to build the specialized hardware. Any system processing limitations would be governed by the choice of minicomputer, which for some applications could even be combined with the Host computer.

The task of researching the choice of a suitable minicomputer would be significant and the final choice may have implications on system acceptability. This solution was certainly technically capable of handling any proposed mainline requirements by way of system expansion. Furthermore progression through a family of minicomputers of increasing capability probably provides for more flexibility than any other approach.

5.2.3 Proprietary Bus System and Hardware

In a small microcomputer system the concept of a System Bus might be limited to the simple and straightforward interconnection of a few integrated circuits. But as the complexity of the system grows, this interconnection becomes a non-trivial concern.

Several bus standards existed for which off the shelf hardware could be bought to configure a system. Such a solution would be very attractive as selection of a Z-80 developed bus would lead to a design logically similar to the previous DCP. Work would be required in the following areas:

a) hardware and bus system
b) software implementation
c) specialized interface hardware
d) packaging

5.2.4 In-house Development of a Suitable Motherboard System

This approach follows the guidelines laid down in the previous sub-section; however, a major difference would be that Glenayre would undertake the development of the required system components. This would involve a large amount of effort in the following areas:

a) system design
b) software design and implementation
c) hardware design and development
d) packaging design

While this approach would share many of the potential benefits of the proprietary system, the effort required to realize a design would be extremely high. This would particularly be so in the case of developing the required hardware and packaging designs. In fact this approach would lead to maximum hardware design effort in comparison to previous approaches. The software requirements in comparison would be relatively moderate provided the Z-80 were used as a CPU and an industry standard bus were adopted. Careful design in this respect would allow the use of existing operating systems and program generation facilities.

In terms of the overall system the implementation time would probably be considerably longer than with any of the preceding approaches. The final design would provide the required expansion capability for mainline application and the long term outlook for such a product would be promising. This approach on the surface looked quite attractive although tight time scales for system implementation were an all-constraining factor. This approach was viewed with caution as it contained many unknown factors which could adversely affect system implementation.

5.2.5 Final Design Evaluation

In evaluating the proposed design approaches several factors were considered as being of paramount importance. These were:

- Time scale for design realization
- Resources required for design realization
- Compatibility between new and old design
- Flexibility and expandability

A comparison of the different systems on this basis quickly revealed that the first approach and the last approach would not represent a satisfactory solution to the problem. The main factor against these being the time-scale for their realization; futhermore, the first approach did not offer any facility for expansion.

The minicomputer solution at first seemed to be the more attractive of the two remaining and the immediate purchase of a machine would allow for the earliest start to software development. However, major drawbacks remained in the considerable design of circuitry to interface with the communications system and the incompatability with Z-80 based systems. Furthermore, a survey of different minicomputers and interface hardware revealed that procurement times would be longer than originally anticipated.

Attention was thus directed towards a design solution using one of the industry standard bus systems and component families. This design had the edge in terms of technical suitability, availability and cost be virtue of the myriad of off-the-shelf hardware and software available. Considerable time was spent surveying different bus systems with final choice resting on the Intel Multibus by virtue of its well designed and thoroughly specified bus standard. Also compatibility with this bus was offered by several Z-80 based single board computer (SBC) families as well as the Intel iSBC80 components. The Multibus based system is also very expandable and would support efficient multi-processor operation using standard components.

In view of these facts the proposal by the design-review team was that an Intel Multibus based system be adopted as the basis for a DCP system and furthermore that off-the-shelf components for CPU, memory, input/output, power supply and packaging should be used. The design of any special purpose hardware would be kept to an absolute minimum. As far as possible techniques used in the previous design should be incorporated in the new system, particularly in view of the investment made in using the Z-80 microprocessor.

A system design and detailed hardware design were prepared to meet these requirements. The resulting DCP hardware is described in the next section.

5.3 DCP Hardware

The redesigned Data Collection Processor is a general purpose computer consisting of a CPU, memory, input/output and specialised interfaces. The system uses the Intel Multibus interface between each of these components.

The various logic boards are mainly proprietary items chosen from the large selection of such Multibus compatible boards. The following subsections describe the various components of the DCP system in more detail.

5.3.1 Central Processor Unit

The processor board is the Heurikon MLZ-90 single board microcomputer, which uses the Zilog Z-80A microprocessor running at a clock frequency of 4 MHz. This processor uses a 16 bit address bus and an 8 bit data bus. The standard Z-80 instruction set of 158 instructions is provided. This set utilizes 8, 16, 24 and 32 bit instruction lengths and is extremely flexible and efficient.

The CPU board features up to 64K total on-card memory with a user selectable mix of ROM and RAM. Of the nine memory sockets provided there are eight for RAM or ROM and one solely for ROM. There is a maximum capacity of 8K bytes RAM per socket using either byte-wide static or pseudo static RAM chips.

Memory management allows for programmable address mapping of RAM completely under software control. Any 8K block of bus address space may be mapped or relocated into any 8K block of CPU address space. Likewise any 4K block of on-card address space may be mapped into any 4K block of CPU address space.

Input/output capability is provided on-board by four 8 bit parallel ports and two serial ports. The parallel interfaces feature software programmable input, output, or mixed modes. Serial ports use an RS232 interface in either asynchronous or synchronous modes. All baud rates are determined by a software controlled dual baud rate generator. All unused I/O device addresses are available for off-card use.

The processor board bus interface is Intel Multibus compatible with a 20 bit memory address space allowing a 1 megabyte address capability. Four software programmable modes of operation determine bus operation hierarchy. This bus provides the processor with the required communication to and from the other elements of the DCP system.

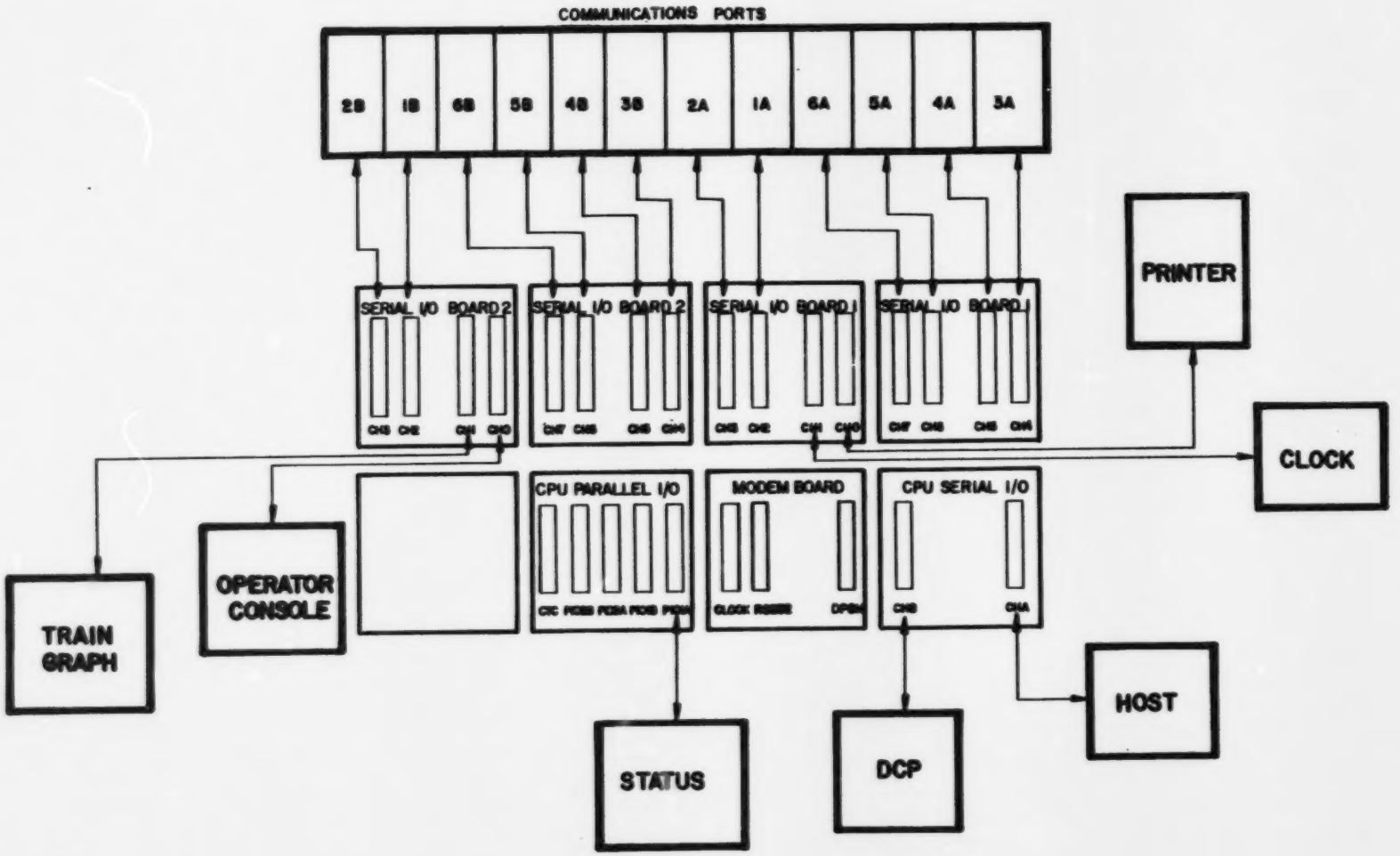


Figure 5 - LIC DATA COLLECTION PROCESSOR (BLOCK DIAGRAM)

5.3.2 RAM Board

The DCP uses the National BLC 032 dynamic RAM board, providing up to 32K bytes of read/write memory contained in four banks. The RM array can be expanded in 16K increments to provide 48K or a total of 64K bytes of storage.

Three tri-state bidirectional buffer/latches interface all data in or out of the memory banks to the system multibus. All command, address and data signals to the bus are TTL-level signals. The board contains four major functional areas as follows:

- address control
- memory storage
- operation control
- data input/output control

Two such boards were allocated to each DCP to provide a basic memory space of 64K bytes which can easily be expanded in 16K steps up to a maximum of 128K bytes. This memory is in addition to the RAM space available on the MLZ-90 board and gives the DCP a total 192K byte RAM capability. The ease with which this memory can be expended will be an essential feature of more advanced applications of the DCP.

5.3.3 ROM Board

The Intel iSBC464 board provides up to 64K bytes of read only memory using other PROM or ROM chips. The board capacity is determined by the type and quantity of the PROM or ROM devices installed. The board is capable of operation in both 8 bit and 16 bit modes, while only the former is used with the Z-80 based processor.

In addition to mode selection the iSBC464 provides four other user selectable features for optimum versatility:

- base address selection
- page address selection
- RAM overlap indication
- access time selection

As with the RAM boards, two such ROM boards are allocated to the DCP. The devices selected for the board were the 2732 type PROMs of 4K x 8 bit structure, thus providing each board when fully fitted with a maximum of 64K bytes of PROM. The use of u.v. erasable PROMs would provide the necessary reprogramming capability during development and debugging.

5.3.4 Serial I/O Board

The National BLC 8538 board provides 8 fully programmable synchronous or asynchronous serial communications channels with an RS232C interface. Each individual channel provides two interrupt requests with distinct priorities.

The overall functioning of the board is divided into six major functional blocks:

- board selection and bus control
- interrupt control logic
- USART control logic
- ring detect logic
- universal synchronous/asynchronous receiver transmitters
- EIA receivers and transmitters

The initial configuration of the DCP utilizes two of these boards to provide a total of 16 serial channels. Four channels are required for local interfaces while the remaining are available for interfacing with remote site base-stations. Duplication of channels to these means that with the present configuration six such remote sites can be handled. However expansion can be easily implemented simply by fitting another serial board of either 4 or 8 channel capability. Obviously such easy expansion is a great advantage over the fixed configuration of the prototype DCP.

5.3.5 Specialized Interfaces

Glenayre designed and built a specialized DPSK modem and clock board to be Multibus compatible and provide the following functions:

a) Watchdog Interval Timer
b) Watchdog non-maskable interrupt (NMI) timer
c) Transmitter Tx 'ON' control circuit
d) Transmitter safety timer
e) Precision oscillator
f) Differential Phase-shift keying (DPSK) modem

The watchdog interval timer and watchdog NMI timer operate in conjunction with the DCP operating system task handler to ensure that in the event of a malfunction the CPU will respond in a safe and orderly manner. The interval timer is programmed via switches on the board such that its period is shorter than that of the NMI timer and it will time out before the NMI timer. When the interval timer times out a low priority interrupt is generated. The service procedure for this interrupt calls a low-priority task to reset the NMI timer and also reset the watchdog interval timer and interrupt. If system operation becomes abnormal and the CPU does not service the interval interrupt, the NMI timer is not reset and will time-out. This will result in a forced non-maskable interrupt to the CPU and execution of a system failure service procedure.

The transmitter-on control circuit is used both to apply a push-to-talk signal to a VHF data radio and to enable the transmitter safety timer. This timer is used to generate an interrupt if the transmitter-on control circuit is energized for a period longer than a safety interval. These features are not currently used in the DCP but provide a useful capability to intereface directly with a UHF radio in the future.

The precision oscillator derives two output frequencies from a 2.4576 MHz crystal oscillator; the frequencies are 153.6 kHz and 9600 Hz. These features are not at present utilised in the LIC version of the DCP.

The modern circuit provides a differential phase-shift keyed data stream passband centred around 1800 Hz and suitable for transmission by radio. The modem may be set for either synchronous or asynchronous operation via circuit board switches. The modem circuit utilizes data contained in ROM to generate the required DPSK waveforms. The modem may be used in conjunction with the transmitter-on control to interface with a radio channel.

While this feature is not used at present it provides the means to interface the DCP with a serial communication facility without the use of the serial I/O boards. This will be a useful feature if LIC utilizes a multidrop communication link in the future.

5.3.6 Intel Multibus Interface

The bus structure provides a common element for communication between the single board computer, memory, serial I/O boards and other interfaces.

The Intel Multibus used in the DCP comprises 16 bidirectional data lines, 16 address lines, 8 multi-level interrupt lines, 5 bus arbitration control lines, and various other control and power supply lines. Some of these lines are driven by tristate devices while others are open-collector driven where wire-ORing of signals is necessary.

Circuit cards or modules that reside on the bus are either masters or slaves. Bus masters can take command of the bus. At least one master module must always be present. Bus slaves, however, simply respond to control lines of the bus and cannot take control.

Since more than one master device might reside within the system, some form of bus arbitration is necessary. This is provided synchronously via the bus arbitration control lines which are "daisy chained", i.e. series connected, rather than bussed on the mother-board.

5.3.7 Packaging

The constituent Multibus cards of the DCP are housed in a Heurikon MLZ-814 fourteen slot rack mounting housing. This housing incorporates an integral cooling fan, power supply and AC line filter. The cards are located horizontally and are inserted from the front. The cards are interconnected at the rear through a printed circuit Multibus backplane that carries all data, address, control and power lines to the cards.

A Glenayre designed rear panel was added to the housing to provide an intermediate distribution connection field for the various I/O interfaces. Connections to and from this panel use 25 pin D type connectors and are grouped and labelled according to function.

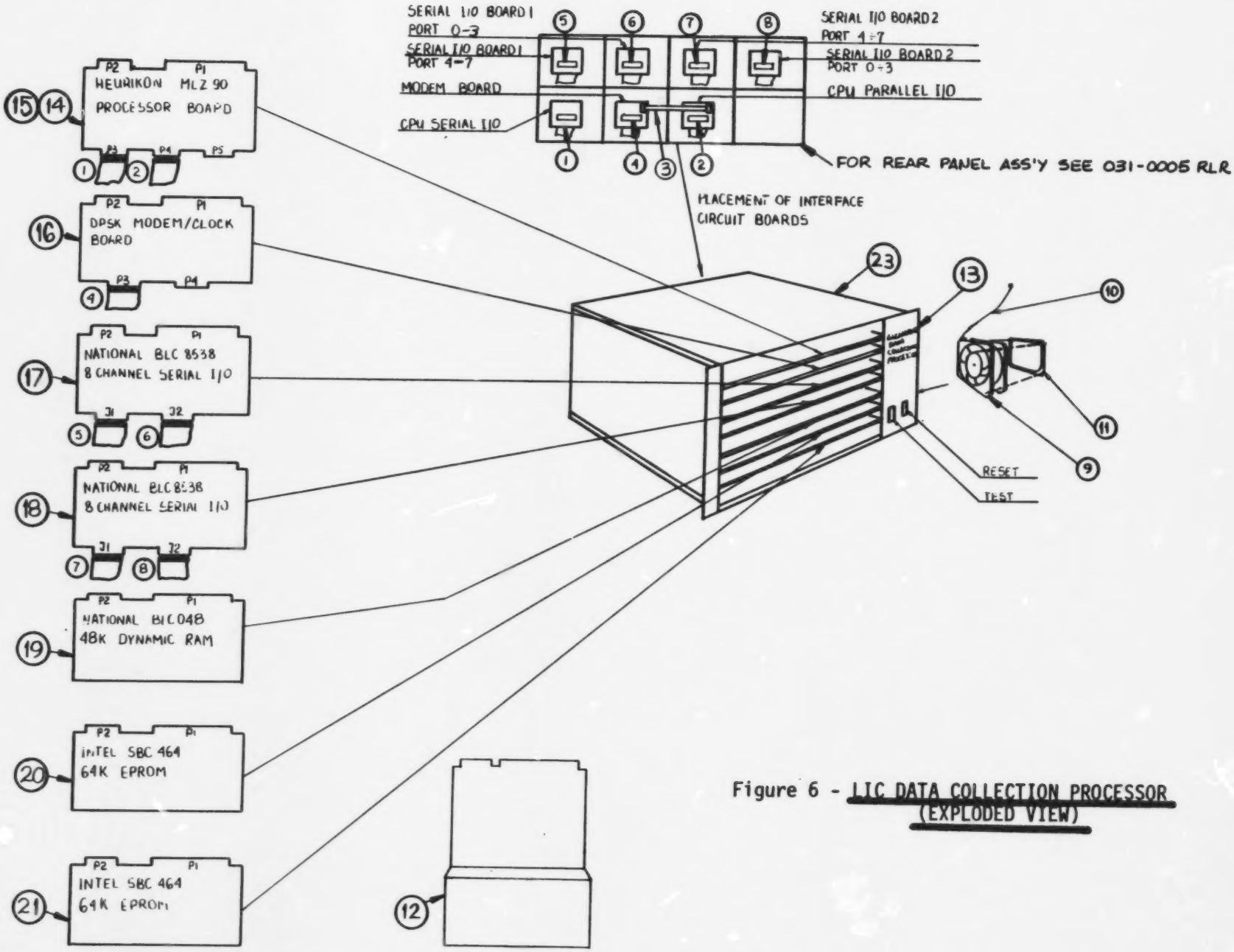


Figure 6 - LIC DATA COLLECTION PROCESSOR (EXPLODED VIEW)

The general layout of the DCP as configured for B.C. Railway is shown in Figure 6.

The package is protected by a hinged front panel which seals the circuit cards and controls from the outside environment. A clear perspex window over the PC cards allows for inspection of various status indicators without opening the front panel.

The complete DCP package may be rack mounted in a standard 19" equipment rack or alternately used in a bench mounted configuration.

5.4 DCP Software Reconfiguration

As a result of the development of the Multibus Data Collection Processor hardware, a software redesign was required. The reconfigured software was based on the requirements of the BCR operational implementation as defined in the DCP software specification. This document describes the functions of the DCP to a level required for its application to the operational installation of LIC on the Squamish sub-division at B.C. Railway.

5.4.1 General Software Design

It was recognized at an early stage of Data Collection Processor development that some formalized process was required for design and coding of the software. A structured design approach based on the work of Constantine, Yourdonn and Meyers in the early 1970's and described in the Glenayre document - "Procedures for Developing Reliable Software" (see Reference 4) was selected. These procedures allow several designers who know little about the target system to design code for programs. The structured design process involves four areas of documentation:

- data flow diagrams
- structure charts
- hierarchical input output structures (HIPOs)
- data definition tables

The data flow diagram is used mainly as an interactive tool to produce an overall structure chart of the software system. This structure chart indicates all modules and data structures to be used in the system. HIPOs and data definition tables in turn describe modules and data structures to the level of detail required for actual coding. Structure charts, HIPOs, and data definition tables along with source listings of the code provide a very complete set of documentation as a by-product of the design process. In addition, the software development procedure enforces some very powerful test functions and procedures.

5.4.2 Safety Software Design

Any system of railroad train control must ensure the safety of trains at all times, both in normal operation and in the event of failure of any component of the system. The LIC system has been developed according to fail-safe concepts after a thorough study of a variety of industry approaches to the problem of computer safety. Appendix B contains a discussion of the overall LIC safety concept, and Appendix C is an analysis of current industry practice.

In terms specific to the LIC system the criteria for fail-safe operation may be stated as follows:-

- Failure of any component or components must not cause the system to believe that a block is clear if it is already occupied or if it could be occupied by a train in compliance with previously issued authorities.

- A failure must not give an engineman cause to believe that he has authority to enter or occupy a block if no such authority has been issued.

It was determined that the primary responsibility for LIC safety would rest with the central computer system. In conjunction with a fail-safe communications network the system must ensure the validity of all data reaching the central office from the field. The central computer system must further ensure that only safe operator inputs are accepted for action by the interlocking system. Finally, authorities and restrictions must be transferred to trains securely and without corruption.

It is evident that the DCP must play a vital role in LIC safety. First, the DCP polls all active ELUs to obtain status and location information. This communication uses a closed loop double handshake procedure and a highly secure message protocol with both parity and CRC code error checking. The DCP performs syntax and context checking of all messages to ensure that they are relevant to the transaction in progress. These procedures assure a fail-safe transfer of transponder crossing data to the central computer system.

In the second place, the DCP performs stringent checks to validate authorities received from the Host computer before they can be transmitted to the ELUs concerned. The DCP maintains a block occupancy/authority data base with an entry to represent each block of track in the subdivision. The same information is duplicated, but under a completely different organization, in the Host computer.

In order for an authority to be transmitted to a train it must pass acceptance tests by both Host and DCP. Duplicate validation by independent and dissimilar processors operating on separate and diversely organized data bases ensures that the probability of issuing an unsafe authority is sufficiently low.

The DCP software also provides for secure transfer of authority to the appropriate train by continuation of the dual thread processing concept. An authority message transmitted by the DCP contains two versions of the Control Point instruction. The first comprises four BCD digits representing the Control Point number followed by two hexadecimal digits which define the direction, route, or switching authority. The second version of the instruction consists of the six hexadecimal numbers which result from application of an error detection code transformation to the first six digits.

The actual message transfer between the DCP and the relevant ELU employs the same double handshake protocol and error detection techniques as are used in transmission of transponder crossing reports. A message received by the ELU is echoed back to the DCP which compares the encoded versions of the instruction in the original and echoed messages. If the comparison succeeds, the DCP transmits an "Execute" message to complete the transaction.

The two versions of the Control Point instruction are used by the ELU to generate a single 40-character line of locomotive cab display data. The dual thread processing concept is maintained, however, in that one version of the instruction leads to a display in numeric and abbreviated form while the other version causes the same information to be displayed in spelled-out form. This procedure provides cognitive diversity to the engineman's display such that if an error has occurred the probability of a readily observed discrepancy in the display line is very high.

In conclusion, the philosophy which underlies the design of LIC safety software is to provide wherever possible duplicate and diverse program paths to the same end. The results arrived at by both paths must agree entirely in order to validate the final outcome. Program design and coding is carried out by independent teams, and, to a certain extent, the safety systems are implemented on two diverse processors. In this way the probability that the overall LIC system will enter an unsafe state as the result of a failure and that the unsafe state will not be detected is extremely small.

5.4.3 Software Tasks

Tasks are usually defined as independent processes that share the processor with other tasks in the system. The DCP system as defined for the operational implementation on B.C.R. has twelve main tasks each assigned to a logical area of memory called a bank. The maximum configuration of the system allows for a full 1 megabyte of addressable memory. The memory mapping required to select any bank is completely controlled by software.

Insofar as the B.C.R. application software is concerned, the basic tracking base-line system has been enhanced by the provision of cab-signalling control and safety tasks. This brings the level of implementation of the system up to level 2 for manual block cab signalling as defined in section 3.1. The proposals for further development to higher levels of operation will be discussed later in the report.

The following paragraphs describe the major tasks of the re-organised DCP software structure as designed for implementation of the B.C.R. operational system.

(a) Receive Task

There are six receive (RX) tasks, one for each of the six radio sites on the Squamish subdivision, i.e.:

- North Vancouver
- Watts Point
- Whistler
- Pemberton
- Spetch
- Mission Mountain

Each task operates identically using all the same modules. The receive tasks are started at power-up and run continuously. Each task is interrupt driven and retrieves data until it has all of the blocks of a message. The task checks the received data for context and syntax together with BCH errors.

Processing of valid messages results in the data being copied to the message buffer, unless the message is a speak-up in which case the speak-up task is called. If the message has a significant importance it will be reported on the DCP printer.

(b) Speak-up.

When a speak-up is recorded from an engine or caboose this task searches the unit file to see if the DCP already has a record for the unit. If it doesn't, a unit record and train record are created. The train is called a provisional train and a report is queued for transmission to the Host computer.

The task having noted the presence of the unit in LIC territory interjects a poll to ascertain its status. From then on the unit will be polled during the regular polling cycle and hence brought under LIC control.

(c) Polling.

The purpose of this task is to maintain communication with every LIC-equipped unit in LIC territory. The task sequences through the unit file, and examines every in-use unit record. If the unit is not a middle of train unit a polling message is sent to the unit, thus initiating the polling transaction. The unit addressed replies to the poll with its speed, odometer, transponder crossings and status information. Middle of train units are also polled every fourth cycle. After the entire unit file has been examined, the task waits five seconds to allow any speak-up to be received and then resumes polling.

This task also contains the two forms of routine for carrying out odometer calibration on a train's lead unit. Simple calibration occurs when the unit receives a mileage associated with a certain transponder in a message from the DCP. Once the transponder is detected the unit will adjust its odometer accordingly. Likewise full calibration occurs when the DCP requires that the unit recompute its odometer correction factor at a certain transponder.

(d) Host/DCP

Three tasks process all message transactions between the Host minicomputer and the DCP. They enable the DCP to receive data, directives, and operating authorities and to send data to the Host on request. The Host messages fall into three categories, each of which is handled by a separate task.

First, data requests are handled by the Host 1 task which is also responsible for message transmission and reception, initial error checking, and assignment of messages to the correct task for processing. Based on the code returned by the relevant tasks, Host 1 builds an Acknowledge message and transmits it to the Host.

Second, command messages are passed to the Host 2 task which checks for syntax and context errors and performs conflict checks on all movement authority commands. If an error or conflict is found, Host 2 returns an Acknowledge code rejecting the command. If the command is acceptable and safe, Host 2 constructs the appropriate message to be transmitted to the ELU and queues a call to the Interject task. In the latter case Host 2 also returns an Acknowledge code which indicates that the message was accepted.

Finally, data update messages are processed by the Host 3 task. These messages are sent at system initialization and at powerup after DCP failures and are used by the DCP to form its initial data base. Updated messages are also used to add trains to or delete them from the train file and to modify the occupancy/authority data base. These messages are checked for safety and conflicts, and Host 3 returns an Acknowledge code to indicate acceptance or rejection of the message.

(e) Interject

Interject is called whenever the DCP wishes to send a message other than its normal polling request to a unit. The task will interject the message into the polling cycle as soon as the polling task has finished its current transaction. Interjected messages are prioritized according to the following order

1) Commands
2) Diagnostics
3) Full calibration
4) Simple calibration
5) Calibrate status

The interject task sends the message and waits for a reply. Processing of the response varies with the transaction being processed and the results of the communication with the unit. After processing is complete, if no further transactions are queued for interjection, the unit is replaced on the polling list.

f) Transponder Task

The task is used as an interface between the DCP software and the DCP track model. The track model is stored in RAM dedicated to the transponder memory bank and can only be accessed by this task.

Three basic functions are performed: resetting the track model; adding a transponder record to the track model; and retrieval of a transponder record from the track model. The task expects to be passed a parameter indicating which function is to be performed.

(g) Operator's Console

The operator's console task handles the interface between the DCP and operator's terminal and allows for the input of various commands to the system. The various commands provided allow the operator to solicit information regarding LIC operations, to carry out diagnostics, or to reconfigure the DCP output ports.

(h) Traingraph

The traingraph task provides a hardcopy printout or display of train movements on the basis of the distance travelled versus time. The train's position and identity are shown at intervals of five minutes. A single location shared by two trains, e.g. during a meet, is depicted by a special "multiple trains" symbol.

The task may direct the traingraph display either to the operator's console or to a dedicated hardcopy printer.

(i) Reports

The reporting task generates printed reports of significant events in the system such as speak-ups, addition and deletion of trains, unit failures etc.

(j) Occupancy/Authority

Task keeping track of all the occupancies and authorities held by trains in the system under LIC control. The task interprets occupancy or authority updates for specific trains and enters the required authorities and occupancies into the database. The actual blocks concerned are determined from the control point and authority or occupancy passed to the task.

(k) Inter DCP

The task handles communications between the on-line DCP and the standby DCP, thereby enabling the update of the standby system every minute. The task also handles functions in the opposite direction from the standby to on-line DCP. In this manner the standby to on-line DCP. In this manner the standby DCP can receive updated information and maintain a current database. The task implements the communications protocol between the two DCP's.

(l) Clock

Task receiving the clock signal from the serial line clock and providing the DCP with real time data for the sign-on message, printed reports, etc.

(m) Watchdog

This task resets a timer within which all tasks may be executed. The watchdog task has the lowest priority; thus if any of the tasks do not complete execution within the allotted time, the timer will not be reset and will cause a system restart.

5.5 DCP Application

The application of the redesigned DCP was considered from two separately identified viewpoints. The first of these was the requirement for a DCP to fulfill the needs of the operational LIC system being implemented on the Squamish sub-division of BCR. The second was the more general requirement to suit the broad spectrum of applications for LIC on mainline railroads. Such railroads would require more advanced features and forms of control than would be possible with the BCR system.

This section deals with the requirements for these two applications.

5.5.1 B.C. Railway Data Collection Processor

The implementation of LIC on the Squamish Sub-Division of B.C.R. was to be the first fully operational installation of the system. It would require the equipping of thirty-six locomotives and thirty cabooses together with installation of communications equipment and transponders over the 154 mile sub-division. At the dispatch office a central control computer was to be installed to manage train movements.

The heart of the central computer system would be a PDP11/44 Host minicomputer which would provide the necessary control and display facilities. However, it was a requirement that a Data Collection Processor be used as a front-end to the Host, thereby relieving the Host of the task of polling and data collection. The specific tasks of the DCP in this case would be to:

a) Poll each ELU on all trains in the Squamish subdivision
b) Maintain a train database including engine identification, location, speed, direction and equipment status.
c) Collect OS data each time an ELU reports a transponder number.
d) Check received transponder numbers against the track model and report any discrepancies.
e) Monitor odometer accuracy and transmit calibration information to an ELU automatically when required.
f) Select the appropriate drop-repeater radio site giving coverage corresponding to an addressed trains location.
g) Establish communications with and add to the polling list any ELU which transmits a 'speak-up'.
h) Alert the Host when a speak-up occurs.
i) Transfer to the addressed ELU with high security any movement authority or directive information generated in the Host.

The central computer configuration shown in Fig. 7 shows how the DCP acts as a front-end to the Host. Also indicated is the provision of standby hardware that can be brought on-line in the event of a failure.

The specific hardware requirements for the DCP for this application fall into two main categories: memory and I/O allocation. Memory size would be determined to a large extent by the applications software task sizes. The DCP is capable of addressing up to 1 Megabyte of memory which can be configured in any desired proportion of RAM and ROM.

Input/output capability requirements were dictated by the various peripherals and communications channels required by the system. These are summarized as follows:

- Dual voice channels to radio repeater locations at North Vancouver, Watts Point, Whistler, Pemberton, Spetch and Mission Mountain. The DCP would require serial output ports operating at 300 baud to 6 group A (ch) modems and 6 group B (ch) modems. This will provide the DCP with total radio coverage over the entire Squamish Subdivision with full duplication of channels.

- High speed serial interfaces operating at 9600 baud to link the DCP with the Host and also with a standby DCP.

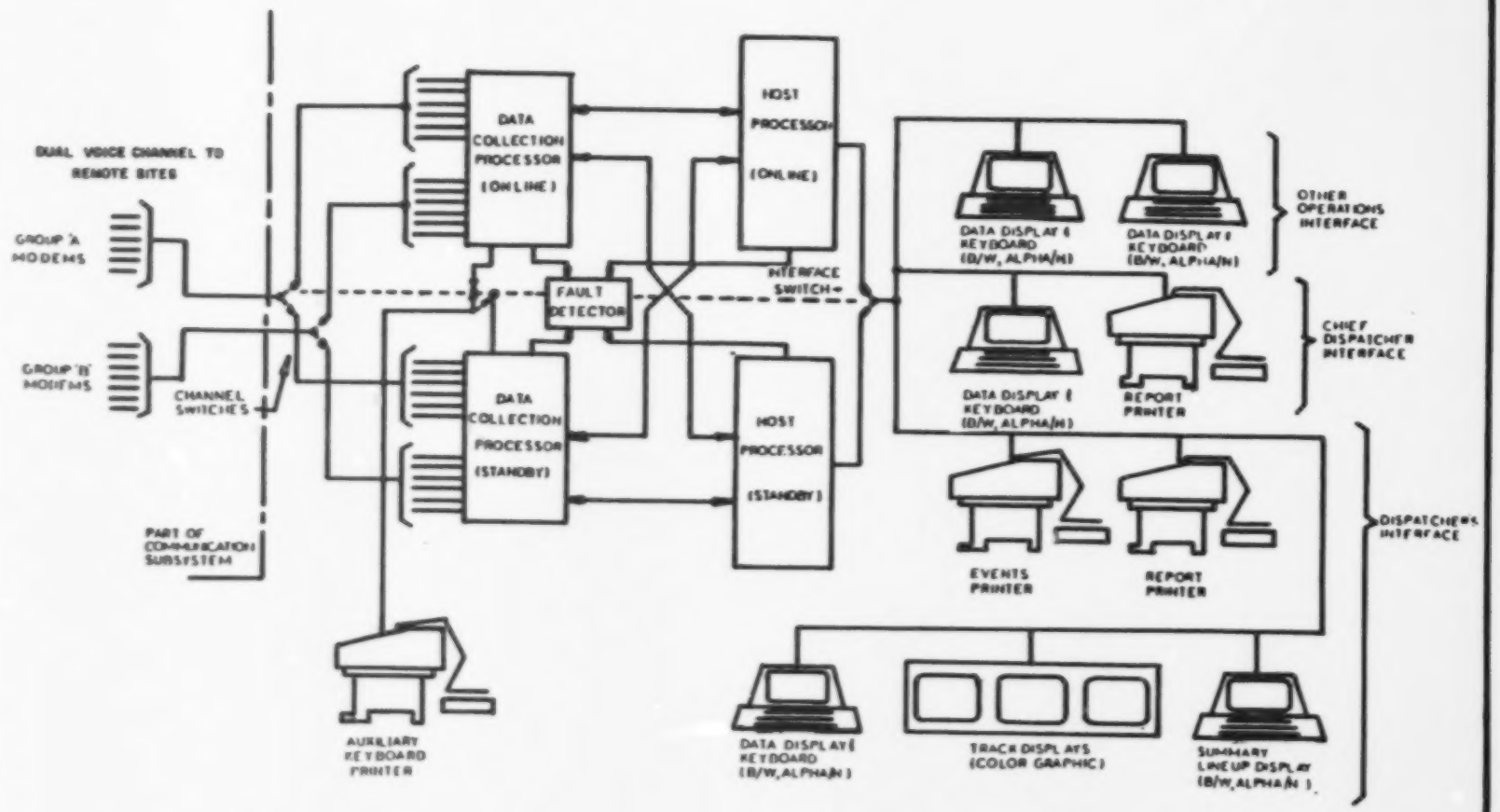


FIGURE 7 Lic Central Computer Configuration

- A serial interface to an auxiliary keyboard/printer which can be port mapped to provide operator console, traingraph printer, or events printer functions.

- A serial line clock interface to provide the DCP with real-time.

- An eight bit parallel interface to the fault indicator unit which by monitoring DCP health can initiate changeover between the main and standby unit.

- Optional serial interfaces to provide a further two printers which will allow a dedicated port for each of the previously mentioned printer/console functions.

The ability to provide these I/O interfaces was met by allocating two 8 port serial boards to each DCP. This in addition to the two high-speed serial and four 8 bit parallel ports provided by the CPU board met the given requirements.

5.5.2 Mainline Data Collection Processor

The application of LIC to mainline railroads will entail many additions, modifications and changes to the DCP; to a lesser extent the ELU may also require changes of a similar nature. Extending the operational capability of the DCP and consequently that of the whole system will require at least significant memory expansion. This will provide for the storage of new tables such as a speed limit table and also for the accumulation of new information such as power switch indications. Also the control of longer mainline subdivisions may require expansion in the I/O capability of the DCP.

Thanks to the modular nature of the Multibus DCP expansion in both memory and I/O are easily achieved through incorporation of additional PC cards. However, the specific nature of certain candidate extensions to LIC operation for mainlines may require additional charges in the DCP hardware.

Each of the candidate extensions as discussed in the previous part could be easily implemented within the DCP through either memory or I/O module extensions. A brief outline of the hardware requirements for each function follows:

a) Remote train brake applications: Provision of relay contacts within the ELU to activate braking equipment would be the only real hardware requirement for this function. Incorporation of the necessary control software within the DCP may require additional memory capacity.

b) Provision in the ELU of updated speed limit based on track location: the main requirement here is the additional memory required to store the necessary speed limit tables. A significant amount of additional processing would have to be carried out in both the DCP and ELU. Messages between the DCP and ELU's would have to be modified to incorporate the additional information.

c) Monitoring of speed limit versus speed: providing both previous functions have been implemented. This function can be implemented without any further changes to the DCP and ELU. As previously though there may be some additional memory capacity requirements.

d) Prediction of braking distance: this function would be software oriented and would only affect hardware insofar as memory capacity is concerned. The necessary software algorithms for predicting braking distance could be incorporated either in the DCP or alternately in the ELU.

e) Use of predicted braking distance to determine safety approaching a stopping point: once the braking distance has been calculated, software within the DCP or ELU can monitor the residual distance versus speed. Linkage with remote braking functions could be provided to enforce braking according to calculated braking profiles. Again this function is totally software based and does not have any real effect on the DCP hardware.

f) Remote control of switches: as far as the DCP is concerned this feature may require significant changes to the hardware. The additional burden of polling switch field equipment may be too great for the CPU to handle. The addition of a further processor board dedicated to this task may be a solution. By virtue of the Multibus DCP design, multiprocessing is fairly straightforward and would overcome the processor loading problem. It may also be required to expand the DCP I/O to incorporate dedicated communications channels for power switch messages.

Obviously this function would not affect train on-board equipment at all; however, a version of the ELU would have to be developed as a field controller for the power switch machines. This would be a significant development task, although functionally the ELU is already close to the requirement.

It should be noted that the inclusion of several of these additional functions together may overburden the DCP's processor. The efficiency of the software and communication protocols will also have a significant effect here and only by further evaluation of the hardware can the upper limit of capability be defined. As previously mentioned, though, should this limit be approached additional processing power may be easily incorporated into the DCP.

There remains somewhat of a problem though if the DCP becomes too complex, especially as it is a ROM based system. The DCP, it must be remembered, is first and foremost a front end processor to the Host minicomputer.

5.6 Program Generation Facilities

5.6.1 Program Language and Compiler

The requirements for the DCP were for a large and solid-state memory. Also the various functions of the DCP would remain fixed for each application. A compiler language, generating a native microprocessor code that is reentrant and ROMable meets the requirements for solid-state memory and fast operating speed under repetitive tasking conditions.

PASCAL was chosen as the programming language for several reasons. It is widely supported on all popular microprocessors and provides a high degree of portability by virtue of single author standardization. In addition, this language is ideal for the structured design approach used for developing the software.

Version 3 of the PASCAL/Z compiler was used to generate ROMable code for nearly all the task modules in the LIC system. Several changes were made to the standard form of PASCAL/Z to enable user specification of stacks and global data address space. In addition, some library routines were modified to prevent calls to disk I/O and floating point routines.

As the system data base grew towards its final configuration, it became evident that the symbol space provided by even the largest 54K version of the compiler was insufficient. Therefore, a special version of PASCAL/Z having all floating-point and I/O support deleted was purchased. This version accommodates all of the global data and will compile all modules except those with very large local data declarations.

A PASCAL pre-processor utility was written to simplify inclusion of commonly used segments of code such as global data definitions. This pre-processor was also used to reduce symbol space requirements by eliminating all constant declarations.

5.6.2 Operating System

A real-time multi-tasking execution program for the DCP was required to supervise the orderly execution of its applications software, input/output and interrupts. Because of the industry wide recognition of the Z80, there were many such commercially available programs. The decision to buy rather than write was easily made since there is little economy in re-inventing the wheel.

A purchase decision was taken to acquire the AMX operating system available from KADAK Products Ltd. VANCOUVER, B.C. The following factors were considered:

- KADAK Products as a local supplier with an excellent reputation ensuring good accessibility and support
- the AMX program is based on concepts proven over a ten year period
- AMX is economical in its requirements for program storage (1300 bytes ROM) and data storage (44 bytes RAM)
- AMX supports high level or assembly language user programs, and is compatible with Microsoft, Fortran-80 and Intel PL/M-80.
- KADAK Products was willing to give additional support in providing source listings and introducing certain modifications.

The AMX operating system provided by KADAK Inc. was used to provide a real-time processing environment. Two GLENAYRE specified additions to the operating system were made by KADAK. A facility for controlling bank-switching according to a user-supplied memory configuration was added to permit use of the DCP bank-select mechanism. A PASCAL/Z interface was written to allow AMX system calls by PASCAL programs.

These two new components along with the established AMX modules (terminal interface and time/date module) were tested with special testing software as soon as hardware was available. Only one minor problem involving the handling of circular lists was discovered and fixed.

AMX must be configured to suit the user's particular hardware and software configuration. This configuration involves the writing of code to handle interrupts, input-output, hardware initialization, task definitions, stack definitions, timer definitions and data initialization. Most of this code, with the exception of the data initialization routines, was written in assembler language.

A set of PASCAL-callable utility routines was written to provide standard I/O functions, mostly related to the operator's console and the printer. These routines, while not strictly part of the operating system, are included in the root that resides in every user bank. This root occupies 8 kbytes of program and 25 kbytes of global data. Of the remainder, 284 kbytes is available for applications tasks. Tasks that do not fit in a single task space must be divided into two or more chained tasks.

5.6.3 Hardware

The following equipment was purchased by Glenayre for engineering use and was made available for program generation.

D88/1-64-1 Dynabyte Inc., Z80 4 MHz Central Processor, configured 64 kbytes of factory installed RAM memory. Standard facilities:

- 2 Serial I/O Ports
- 1 Parallel I/O Port with full Handshaking Logic
- Fully compatible S-100 bus
- Jump start
- Vectored Interrupts
- Real Time Clock
- Pre-regulated Power Supply

DB8/4-2-1 Dynabyte Inc., dual system, double sided double density floppy disk drives

DB8/6-32-1 Dynabyte Inc., one fixed (16 MB) and one removable (16 MB) hard disk cartridge module c/w controller, cables, and terminator.

X8-20-0012 CMD cabinet for above.

X8-30-4810 (three off). Total of 144 kbytes of additional RAM memory.

800394 Dataport Board (8 port serial I/O).

CP/M 2.12A software

The above Dynabyte system is used with Volker Craig Video Display Terminals and keyboards and a Texas Instruments printer. In addition, a Millenium stand-alone emulator was acquired.

The selection of the Dynabyte system was made as the result of a survey of available systems, which boiled down to three proven main manufacturers: Altos, Cromemco and Dynabyte. Dynabyte was selected after completion of factory visits and surveys of each supplier's facilities.

Dynabyte was selected in that it offered:

- large hard disk capability
- additional floppy disk flexibility
- multi-user hardware and operating system
- an operating system that was widely used with many compatible programs available e.g. Wordstar, Pascal, etc.

6. DCP EVALUATION

6.1 System Testing

6.1.1 DCP Hardware

The hardware components of the new DCP consisted primarily of a standard Multibus backplane and a number of off-the-shelf circuit boards. Initial hardware tests indicated that all components functioned according to specification. Some subtle problems arose, however, when the DCP software was installed and tested. The laboratory tests were carried out with the help of an ELU simulator at first, then with a single ELU, and finally with three or four ELUs at the same time. In order to simulate radio zone overlap, two or more DCP receive data pins were jumpered together.

The DCP applications programs were not changed appreciably when they were transferred to the new hardware. The bulk of the DCP software is stored on memory cards accessed via the Multibus, and this configuration tended to increase the time needed to access certain program areas. As a result of the timing problems which ensued it was found necessary to alter the priorities of certain tasks to maintain system performance.

The DCP interface software, on the other hand, was largely rewritten for the new DCP. The operator interfaces (terminals, printers) were tested with a Decwriter hard-copy terminal and presented no problems. Similarly, the 9600 baud Host/DCP serial interface operated satisfactorily.

By contrast, the radio/modem ports did show a problem. It was found initially that the system was unable to handle simultaneous data reception from more than two communications sites in spite of the relatively low (300 baud) data rate in use. The difficulty was caused by the limitations of the Multibus interrupt structure. The DCP modem ports were on 8-channel serial I/O boards accessed via the Multibus. Each board generates only one interrupt signal, and it was necessary for the software to poll each of the 8 ports to determine which had interrupted and the nature of the interrupt. When the interrupt service software and system stacks were moved to the processor board, however, the increase in access speed was sufficient to support the required level of operation.

Upon conclusion of laboratory testing, the DCP was delivered to B. C. Railway and installed for operation on the Squamish Subdivision. No further DCP hardware problems were encountered in the course of field tests (Section 6.2).

6.1.2 Software Tasks

Section 5.4 of this report discussed the overall design of the DCP software. The bulk of the software was written in Pascal, and the KADAK AMX real time multitasking operating system was used. The fundamental testing of the software occurred at the module level. As a standard design policy, calls to a "path" routine are made at every possible branch in the Pascal source code. During tests of a coded module the programmer is required to write test drivers that execute every program path at least once. While this procedure is very time consuming, it does ensure that if the input and output data are properly defined, then the code will execute without error when it is installed in the target system. During actual system integration, in fact, very few Pascal programming errors were found. Most of the problems resulted from improper use of variables, errors in the initial design, linking faults, and the intricacies of real time multitasking.

System integration was carried out in two phases. First, the AMX operating system was tested thoroughly by means of special tasks designed to drive all operating system functions such as input-output, inter-task communication, and task scheduling. These tests revealed one significant error in the interface between AMX and Pascal coded tasks; however the problem was resolved by redesign of the Pascal interface module and redefinition of certain calling conventions.

The second phase of system integration was concerned with task installation and testing. Each task was installed individually and tested as far as possible in a non-multitasking time environment. The process began with the operator interaction task (the only task running after initialization is completed) and proceeded in a top-down manner until the complete task was installed. Modules called by the modules currently under test were represented by stubs until the module under test was bug-free. Similarly, tasks started by the task currently under test were represented by stubs.

The hardware used in the lab for system integration comprised a DCP and its peripherals (operator console and printer); two ELUs (one to simulate an engine, the other a caboose); a Host simulator; and a unit to simulate the Fault Indicator. An interrogator, a programmable transponder, and a pulse generator were used to simulate actual train travel. The debugging tools used were a Z-80 emulator and logic analyzer to track the execution of software, and a serial analyzer to monitor Host/DCP communication.

Testing became considerably more complicated as soon as more than one task was required to run simultaneously in order to proceed. Multitasking problems can be very subtle, and there are no simple methods with which to track down problems that result from improper synchronization, data access conflicts, and the like. Programmers were aided by the use of a path routine which allowed the tester to set breakpoints and/or single step through the path calls described earlier in this section. Nonetheless, this phase of system integration proved extremely frustrating and time consuming.

6.1.3 Control Functions

This section describes the test procedure used to demonstrate the proper operation of the LIC train control functions implemented in the DCP. The test was carried out at GLENAYRE using a Host simulator to generate the control commands and an in-lab ELU and cab display to represent a train on the Squamish Subdivision of B. C. Railway.

The DCP was initialized by transmission of Initialization Begins and Initialization Ends instructions from the Host simulator. A Train List Update instruction caused the train to be entered into the LIC system. The next commands tested were CALL DISPATCHER and CALL DISPATCHER OFF which display a request to the engineman to contact the train dispatcher by voice radio. The final command in the train initialization sequence, ACK WHEN READY, was then transmitted and displayed.

The Host simulator was then used to transmit a series of Control Point Instructions (CPIs). During this procedure it was shown that LIC correctly prevents occurrence of the following events:

- processing of a command before the status of the previous command has been reported to the Host.
- acceptance of a CPI authorizing movement in a direction different to that of the CPIs already in the ELU buffer.
- acceptance of a Restricted Route or Switching CPI while other CPIs are in the ELU buffer.
- acceptance of more than six CPIs into the ELU buffer.

It was then shown possible to remove the last instruction from the ELU buffer provided it was not one of the three CPIs shown on the cab display. The instruction was again transmitted to the ELU. The DUMP BUFFER instruction, which returns the contents of the ELU buffer to the DCP for diagnostic purposes, was also tested.

For the remainder of the control function tests, train travel was simulated by manual waving of the appropriate transponder(s) over an interrogator connected to the ELU. Automatic roll-up of the instruction display was demonstrated at the first "Control Point", and the ELU odometer was calibrated as directed by the CPI.

One of the transponder 'crossings' was omitted at the next Control Point to simulate a missed transponder, and a Manual OS (dispatcher entry of transponder crossing data) was performed. Automatic roll-up was demonstrated at the next Control Point. The last instruction in the ELU buffer was now shown on the cab display. Removal of the CPI under these circumstances requires acknowledgement by the engineman, and this procedure was successfully demonstrated. The last instruction was replaced by a Siding CPI over the same Control Point.

Manual Override was demonstrated. It was shown that this command repeatedly removed CPIs from the ELU until the buffer was empty, and that no further commands would be accepted for that train. The train was then deleted from the system.

The train was re-entered, re-initialized, and sent a Switching CPI. While this CPI was displayed it was correctly shown that no other CPIs would be accepted, nor could the instruction be removed by a Manual OS. Proper removal of the instruction by means of a CPI Remove instruction was then demonstrated. A CPI in the direction opposite to the original "movement" was displayed and correctly rolled up at the appropriate CP.

The "train" was then modified so that the original ELU became an end-of-train unit, while another ELU became the lead unit. An ACK IMMEDIATE instruction was transmitted to show how an ELU with cab display could be configured as an end-of-train unit. The second ELU was removed, leaving the train with only an end-of-train ELU. It was shown that operating directives for this train were no longer accepted, but Manual OS for an end-of-train unit could be performed.

In the final control demonstration, a FORCE FAIL instruction was shown to blank the cab display and to prevent further transmissions from the ELU addressed.

6.2 Field Testing

Field tests of the redesigned DCP took place in late 1982 as part of the LIC Full Tracking tests on the Squamish subdivision of British Columbia Railway. A full description of these tests is contained in Reference 5. The overall objective of the Full Tracking tests was to evaluate the LIC train tracking functions under operational conditions with a single Host/DCP central computer configuration. The DCP was thus called upon to manage transponder reports, locomotive odometer calibration, and polling and radio communications with all trains. In addition, the DCP was required to communicate continuously with the Host processor.

The tests covered four areas: transponder reporting, odometer calibration, communications coverage, and train location. The remainder of this section outlines the procedure followed in each test and gives a brief description of the results. The following section (6.3) contains an overall evaluation of the new DCP and compares its performance with that of the previous design.

6.2.1 Transponder Reporting

The DCP events printer records the details of each reported transponder crossing by unit number and time. The minimum acceptable reporting success rate was a mean of 99.8%, taken over a series of samples of 10,000 LIC operational transponder crossings. The actual rate recorded, averaged over five such samples, was 99.86%, and the transponder reporting function was deemed to have met the requirements for LIC application.

A few problems were encountered, however, in the early stages of the tests. In particular, it was determined that the tendency of locomotives to overhang on curves made the mounting position of the locomotive Interrogator Coil Unit (ICU) quite critical, and British Columbia Railway developed a suitable fixture to standardize the ICU location on all engines. Furthermore, it was found necessary to design the mounting bracket so as to minimize loading effects on the ICU's low frequency RF circuits. The only transponder reporting software problem encountered was a minor error in a Host system file access routine which caused an apparent delay in data transfer from the DCP to the Host.

6.2.2 Odometer Calibration

Previous field tests of the LIC locomotive odometer produced several interesting results. First, it was found that the odometer was more accurate over an extended distance than was the original survey and chaining of the subdivision, and the DCP track model containing the transponder locations was revised accordingly. Second, slight differences between the nominal and

actual diameters of the engine wheels had a significant effect on the odometer readings from a given engine. For this reason a Full Calibration procedure was incorporated to allow measurement and application of a wheel wear factor specific to each locomotive. Finally, in view of the erratic readings attributed to wheelslip and other unknown factors, it was decided to carry out a simple recalibration at any transponder at which the measured and actual mileages differed by more than a certain amount.

The Full Tracking test results confirmed the validity of the above changes, but the increased odometer accuracy made other problems apparent. It became evident that better results could be obtained if a given engine was not required to compute its wheel factor at the start of each trip but rather was assigned a factor by the DCP. The most troublesome inconsistencies, however, were observed when engines operated at low speeds. The problem was not found to occur on all units and was eventually traced to a specific type of axle pulse generator. Application of a signal conditioning circuit modification to these generators cleared up the difficulty.

6.2.3 Communications Coverage

Maintenance of reliable UHF radio communications between one or more fixed sites and a train moving in mountainous terrain is a difficult problem. A theoretical analysis of LIC requirements indicated that in order to handle around 20 trains on the subdivision, the number of DCP messages received and acknowledged on the first attempt would have to be of the order of 75% of all messages transmitted.

The remote sites on the British Columbia Railway Squamish subdivision were originally chosen to optimize VHF voice radio communications with trains and thus were suitable for LIC use. Nevertheless, the average communications success rate in Full Tracking did not exceed 72%. Some geographical areas were known to provide extremely poor radio coverage which the railway hopes to improve, possibly through the use of passive repeaters.

In certain areas where the coverage zones of two remote sites overlapped, but neither provided a particularly strong signal, the problem could be compounded by the DCP's choice of site. Further studies are being undertaken to determine the need to modify either the DCP communications coverage model or the software site selection algorithm in order to eliminate this problem.

6.2.4 Train Location

Train location refers to the methods by which LIC provides the dispatcher with a continuously updated picture of the position of each train. Two methods are used: the DCP train graph and the Host colour graphics display.

The train graph is output by the DCP on a dedicated printer at a rate of one line every five minutes. A single line represents the entire length of the controlled territory, with a special character to mark the position of each train within the territory. Over a period of time the changing positions of the printed characters form a graphic indication of train movements in the system. The train graph met specification in the earlier version, but the subsequent redesign of the DCP made it necessary to repeat the test. The results, as expected, were identical.

The colour graphics display is controlled by the Host processor. The display consists of three colour video monitors which bear a scale representation of the LIC trackage. Every main track switch and siding is shown, and all stations and control points are identified. A train is indicated by an arrowhead symbol pointing in the direction of travel and identified by a particular mnemonic. The display format and the evaluation of this part of the system are described in detail in Ref. 5.

6.3 Evaluation

Part 5 of this report showed how the base-line DCP used for the basic tracking tests in November, 1981, provided the necessary functions but fell short in areas related to future expansion. A revised DCP design based on a standard microprocessor bus system was then described, and the additional requirements for mainline railway application were discussed. Part 6 has described the evaluation of the new DCP both in the laboratory and in the full tracking field tests completed in January, 1983.

The results showed that the LIC system met all of the requirements for train tracking except in the area of odometer calibration. Operational testing on B. C. Railway has now proceeded to the LIC train control phase. The revised DCP design definitely proved its worth during the tests in terms of flexibility and ease of maintenance. The DCP now has about 256 K bytes of memory installed, which represents all of the software and data storage required for British Columbia Rail LIC. The processor is able to handle its present load very well.

The new DCP thus is capable of expansion to include further tasks; in the event that more processing power is required, the Multibus design will support multiple processors. It should be recognized that if additional functions are added or major changes are made to the DCP, that considerable systems/software engineering will be required to ensure that the tasks can be handled. However, the potential for growth and expansion definitely exists in the DCP.

7. MAINLINE RAILROAD STUDY

7.1 Background

Canadian Pacific Railway has maintained a particular interest in the LIC System since its conception, and has contributed many suggestions during specification and prototype testing of the system. Their interest is motivated by particulars of their present operations and equipment including:

a) widespread use of radio and microwave communications

b) significant sections where no centralized traffic control system is installed

c) major unit train operations being carried out partly under train order control

The unit train operation, hauling coal between Fording and Roberts Bank, involves train order control over the Fording River, Cranbrook and Windemere Subdivisions between Fording and Golden. The mainline track between Golden and Roberts Bank is operated using CTC.

The high interest in application is partly motivated by a perception that the LIC System can, through detailed operating information collected, contribute to an increase in the cost effectiveness of operations. In addition, the captive nature of the equipment used for unit train operation makes it an appropriate situation in which to implement a pilot LIC installation and evaluate its potential benefits to other and more widespread applications elsewhere in the CP Railway system.

With the co-operation of C.P. Railway, the criteria for application of LIC to mainline operations were defined by a study of the particular requirements of CP Railways Fording River, Cranbrook and Windemere subdivision.

The next section outlines the methodology adopted in carrying out this task.

7.2 Methodology

The purpose of this task was to investigate and acquire an understanding of CPR operating procedures, regulations, and practices on the Fording River, Cranbrook and Windemere subdivisions.

The approach taken was to study general operating procedures as defined by the UCOR and CPR timetables. In addition, information was gained on Train Order and Manual Block Systems of railroad operation, together with the duties and functions of railroad dispatchers.

An initial practical survey was carried out at CPR's Vancouver dispatch office located in Granville Square. This centre controls train movements between Vancouver and Kamloops on the mainline together with various secondary lines. Several dispatchers were interviewed and operation studied for several hours.

The initial survey was followed up by a Field survey in the Kootenay Division of CP Rail lasting five full calendar days.

The following CP Rail officials were interviewed

M. Morrow	Asst. Superintendent of Transportation, Vancouver
M. A. Lypka	Superintendent, Nelson
S. D. Cosar	Chief Train Dispatcher
R. P. Cavanaugh	Night Chief Train Dispatcher
J. Kazacoff	Train Dispatcher
P. Anutooshkin	" "
C. Proctor	" "
M. Wasylik	" "
R. M. Mackenzie	" "
A. Lannon	Road Foreman Cranbrook
J. Cashin	" " "
G. Doover	Mechanical Engineer Nelson
D. Sangster	Communications Technician

All of the staff interviewed were found to be extremely helpful and candid considering the work-load they have.

Train operations were observed from the locomotive cab of Extra 5816 East between Sparwood and Fort Steele, a distance of 77.9 miles (approx. 125 km).

In addition continued consultation with B.C. Rail was carried out to clarify methods of train operation and compare CPR and BCR practices.

The findings of the study were used to prepare a features list/user requirements list for a LIC system suitable for the control of trains on CPR.

7.3 Railroad Profile

The subject of this study is the railway line extending from Fording to Golden on Canadian Pacific Railway's Kootenay division. This particular stretch of line located in eastern B.C. is segregated into three subdivisions, namely Fording river, Cranbrook, and Windemere. The general geographical layout is given in Figure 8.

The line originates in the Rocky Mountains at Fording, the site of an open pit coal mining operation run by Fording Coal. A loop track with sprung entrance/exit switch enables on-the-move loading from coal silos. The line extends east to the Elk River with maximum descending grades of 1.8%. The line follows the Elk River water course south through Clode, Harmer, and onto the Cranbrook subdivision at Sparwood. Spurs serve further open-pit coal operations at Greenhills (B.C. Coal), Line Creek (Crowsnest Resources) and Elkview (B.C. Coal). The line is downhill all the way through to Sparwood with a ruling gradient of 1.8%. The longest grade is approximately 10 miles of length and the sharpest curve is 10°.

The Cranbrook subdivision commences at Crowsnest in Alberta and the line runs down gradient from Crows Nest Pass to meet the Fording River subdivision at Sparwood. The line from here runs west alongside the Elk River to Elko, and the route affords modest gradients with a maximum of 1.4%. The line after having climbed to Elko station descends to the North End of Lake Koocanusa and follows the Columbia River to Fort Steele. Initial down grades from Elko are 1.0% maximum, while running from Bull River through to Fort Steele is at virtually zero grade. The Cranbrook sub-division joins the Windemere sub-division at Fort Steele while the former continues on to terminate at Cranbrook. The longest grade between Sparwood and Fort Steele is 5.75 miles in length and the sharpest curve is 10°.

The junction at Fort Steele allows traffic to move to and from the Cranbrook and Windemere subdivisions. The Windemere sub-division line heads north to Golden along the Columbia River water-course route. Gradients on this section of line are very low, seldom exceeding 0.4%, which is in constrast with the steeper grades of the Cranbrook and Fording River subdivisions. Maximum curvature on this section of line is 10° which it seems is the operating maximum for the lines under discussion. The worst gradients are located either side of Golden Yard and are 1.0% and 0.7% respectively.

The total length of the line from Fording to Golden is 254.2 miles (401 km), being made up of Fording River sub 33.8 miles (54 km), Cranbrook sub 77.9 miles (125 km) and the Windemere sub 142.5 miles (228 km).

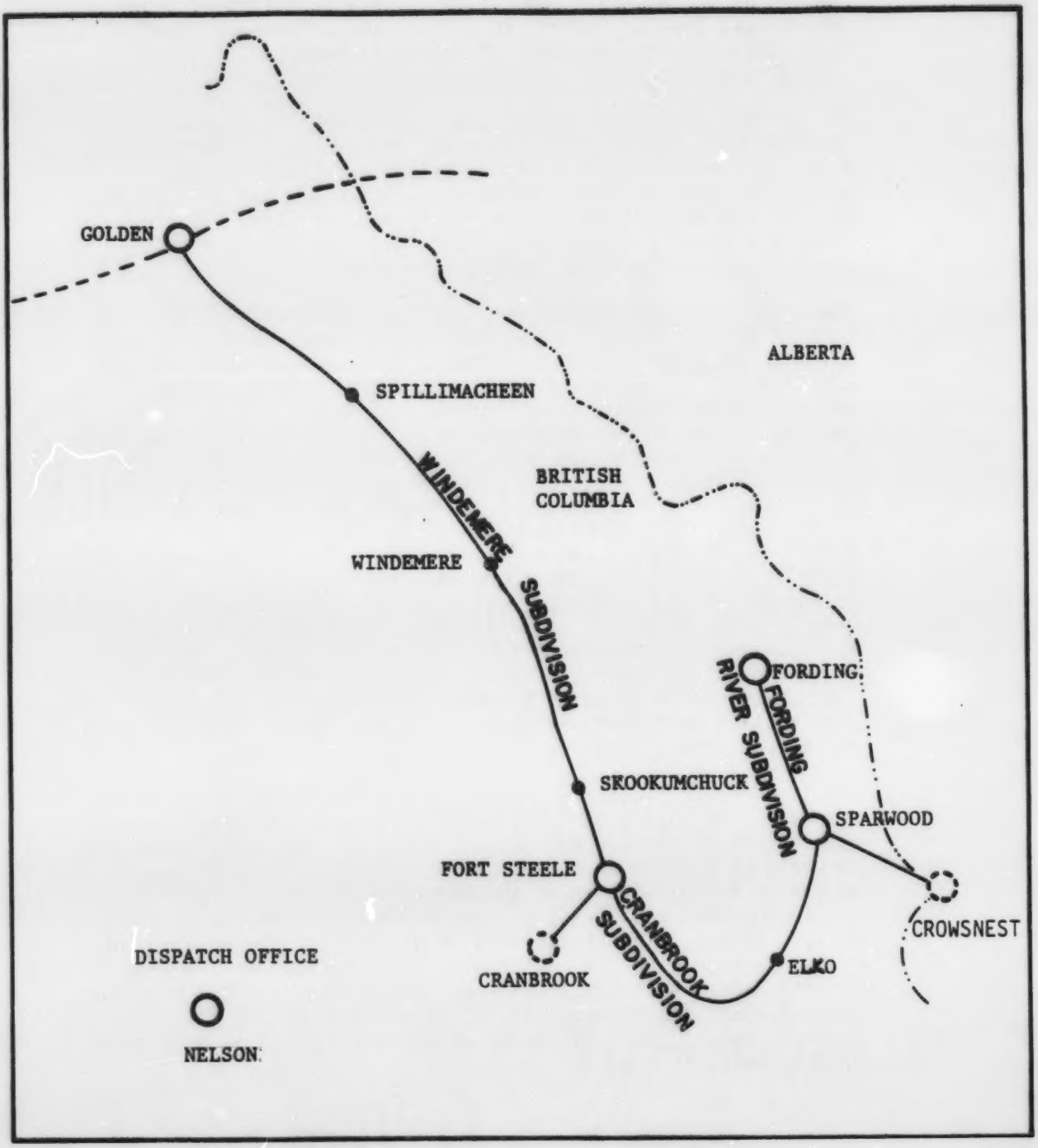


FIGURE 8 - Overview Of Fording-Golden Line of C. P. Rail

At Golden the Windemere sub joins the CPR mainline through the Rockies on the Mountain subdivision. This territory is under Centralized Traffic Control (CTC) from the dispatch office at Revelstoke, and the movement of trains is governed by signal indication.

The primary source of traffic and revenue are the coal mines in the Sparwood, Fording, and Crowsnest areas. Coal from these mines is moved over CPR rails to Golden and thence by the main-line to Mission City where the B. C. Hydro Railway is used to take the coal to the super-port at Roberts Bank. The route takes the heavily loaded coal trains over the second worst gradient on the Canadian Pacific main-line.

Operations are carried out with unit coal trains which are captive between the mines and the Roberts Bank super port. It was planned that the 1400-mile round trip between mine and port would take 72 hours, and that to carry the tonnage originally demanded would require trains of 88 loaded cars. The original payload on the outward trip was around 8000 tons. At present the trains are being operated with 108 loaded cars increasing the payload to 10,800 tons. The cars themselves have a tare weight of 30 tons, so the gross trailing load of these trains is about 14,500 tons. With diesel electric locomotives coupled in multiple unit there is no difficulty in piling on any amount of power at the head-end, and there was certainly a major obstacle in the way in the 1 in 45 ascent from Beavermouth to Stoney Creek, in the Selkirks. Many factors other than tractive effort are involved when trains of such weight have to be hauled and brake-controlled over such severe gradients, gradients moreover that are sited on lines of incessant curvature and physical construction that multiply exceedingly the dangers that would arise from a derailment.

One significant factor is the physical strength of the train drawbar. The centre couplers used by CPR and throughout North America are of massive design, but while all the power necessary to run such a train at 40 mph on the Windemere sub-division can be can be safely applied at the head-end, the drawbar pull from the locomotives could rise to many times that value in climbing a heavy gradient. Thus techniques of distributing power down the train are used with the coal trains from Sparwood and Fording to Roberts Bank. When the service was inaugurated a total of eleven 3000 HP diesels was needed to get up the 2.6% Beaver Hill. However, on the Sparwood to Golden section a total of only four 3000 HP units is required.

FIGURE 9 - C. P. Rail Unit Coal Train (Extra 5806 West)
Sparwood to Roberts Bank

Note: UCOR rule 21 in operation: Extra train will display two white flags and two white lights by day and night.

At present the following is a typical consist for a unit coal train between Sparwood and Golden:-

a) Two/three 3000 horsepower locomotives under control of engineman and regular crew. The leading (Master) unit is equipped with Harris Locotrol and two-way VHF voice radio.

b) 40 - Gondola cars, each conveying a payload of 100 Imperial tons of coal.

c) Two unmanned 3000 horsepower locomotives operated by remote control via robot relay unit.

d) Robot relay unit (car), unmanned, linking the lead and remote locomotives by radio control.

e) 68 - Gondola cars, each conveying a payload of 100 Imperial tons of coal.

f) The caboose, manned by train conductor and crewman who is in two-way voice communication with lead and pusher diesel crews.

The power units for these trains are allocated from Revelstoke and it should be noted that the consists for trains vary according to the loading destination.

Trains destined for Fording Coal have an extra 3000 HP robot unit attached mid-train at Revelstoke. This is necessary to handle the train on the long 1.8% descent from Fording to Sparwood, the extra power being required to give adequate braking capability to the loaded train rather than power for the unloaded train up the incline.

The Fording/Sparwood to Golden Line unit coal trains use the General Motors SD40 model of 3000 HP for these road freight purposes (i.e. GRF30)

The units in use for head-end operation are all equipped with Harris locotrol for controlling robot units in mid-train. Additionally these MASTER control units are equipped with the Vapor TOR II equipment for Train Operation Recording. The Master units so equipped in use on the Pacific region at present are unit Nos. 5800 - 5821 inclusive.

The total number of unit trains in operation at present is about 16 although some of these are not used on the Fording/Sparwood to Golden run. The CPR coal trains in operation at present are designated as follows:

Designation Loaded	Empty	Service	Type
657	658	Coleman to Port Moody	Unit (2/2)
659	660	Line Creek to Port Moody	-
800	801	Corbin to Thunder Bay	-
803	804	Sparwood to Roberts Bank	Unit (2/2)
805	806	Corbin to Roberts Bank	-
807	808	Line Creek to Roberts Bank	-
821	822	Fording to Roberts Bank	Unit (2/3)

* Schedule rules for symbol trains apply (Reference 8).

The number of unit trains operating to Roberts bank is at present under normal operating requirements: about 10. However, short periods of excess demand may cause this to be raised to 13.

Coal is being mined at an increasing number of sites in the Crowsnest/Sparwood area and it seems inevitable that the present number of unit trains will not be enough. The effects of increasing traffic are already being felt on the mainline west of Calgary particularly between Beavermouth and Stoney Creek where progress is slow because of the severity of the gradient and because of the time taken attaching or detaching additional units.

Figure 10 below shows the predicted growth of coal traffic through the Rockies to the year 1990.

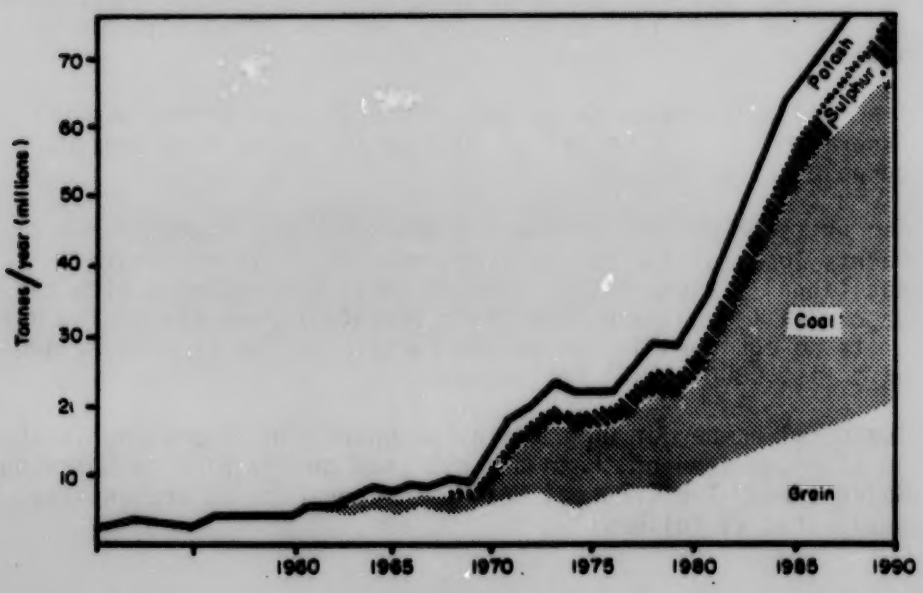


FIGURE 10 - Coal Shipments Across Canadian Rockies

1950 - 1990 (projected)

The forecast minimum coal tonnage to be handled 1981 to 1985 is as follows:

Year	B.C. Coal	Fording	Byron Creek	CNR	Coleman	Rio Algom	Total
1981	8.1	3.9	0.4	-	0.3	-	12.7
1982	8.2	4.6	0.6	0.9	0.3	-	14.6
1983	8.7	5.0	1.0	2.1	0.3	-	17.1
1984	10.0	6.0	2.0	4.5	0.3	(Probable 1.0)	22.8
1985	11.2	6.9	3.0	5.3	0.3	1.0	27.7

Notes - all figures are in MGT
- CNR is Line Creek on Fording-River sub, Byron Creek is at Corbin on Cranbrook sub, Rio Algom is at Sage Creek south of Fernie 14 miles from USA border (see Fig. 11)

It can be seen from these figures that given the maximum loading of a unit train is at present 10,800 tons; by 1985 in order to carry the 27.7 MGT there will have to be 8 loaded coal trains run east each day. Based on the present turn around time this relates to a headway of 2 hours 41 minutes assuming even spacing.

Historical data reveal that the following freight gross tons have been handled over the given subdivision from 1976 to 1980 inclusive:

Year	Fording	Cranbrook	Windemere
1976	3,303,000	22,322,000	18,212,000
1977	5,083,000	23,382,000	20,060,000
1978	5,900,000	26,080,000	22,861,000
1979	5,864,000	27,879,000	23,997,000
1980	6,577,000	25,124,000*	21,727,000

*Note decrease due to B.C. Coal strike Jan. 5th 1980 to Mar. 4th 1980

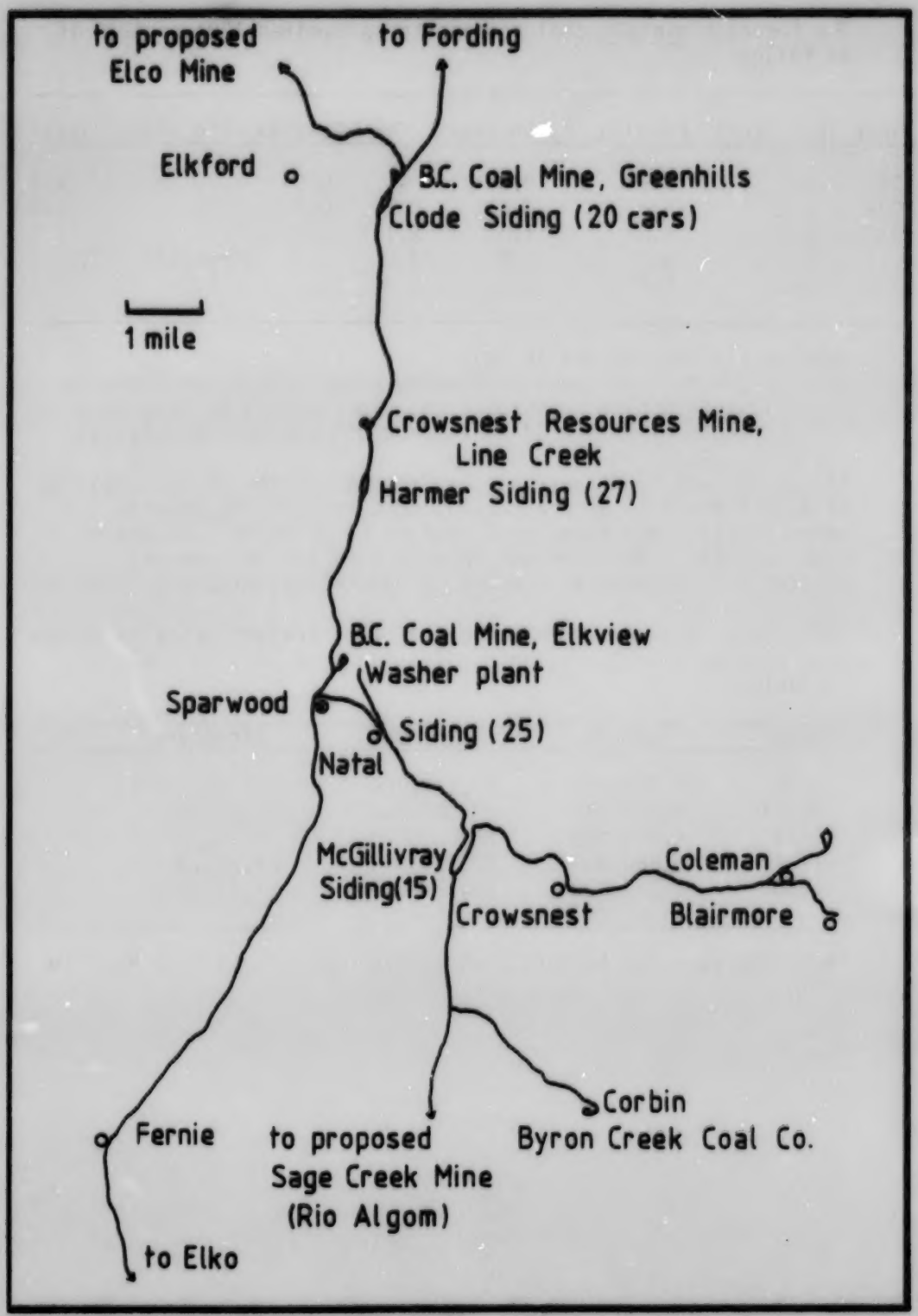


FIGURE 11 - C. P. Rail Facilities Serving Coal Operations in the Sparwood, B. C. Area

The figures at present available for 1981 give the following number of movements:

MONTH	CRANBROOK SUB Average Daily Train Movements	CRANBROOK SUB Range of Values	WINDEMERE SUB Average Daily Train Movements	WINDEMERE SUB Range of Values
July/81	16.3	11 to 21	11.3	7 to 16
Aug/81	15.7	11 to 21	10.2	7 to 15
Sept/81	17.4	8 to 27	11.5	7 to 15

The projected overall traffic levels based on this performance and projected coal traffic gives the following levels by 1985:

Cranbrook sub - 25-35 daily movements
Windemere sub - 19-23 daily movements

It can also be expected that if coal traffic grows as expected the 1980 haulage figures will be in the order of double those for 1985. This will represent traffic in excess of 60MGT per year.

General experience on North American railroads has shown that the limits of single track capacity fall somewhere between 30 and 43 million gross ton miles per mile. This fairly wide range reflects the different operating characteristics found on most railroads. It could be expected that on the Cranbrook sub where sharp curves and gradients mean lower train speeds, the figure will be towards the lower figure. Comparing this figure with the projected levels immediately highlights the problem. Only by strategicially and progressively locating 12 to 15 mile stretches of double track throughout the territory can operating viability be maintained above the 43 MGTM per mile level.

While coal traffic accounts for a large proportion of traffic on these subdivisions there are several other types of train worth noting.

Symbol trains handle a variety of traffic to and from locations all over Canada, the objective being to place all cars on schedule at the consignee's siding. The minimum goal is to place on time 80% of Group A traffic. Several of these trains run over Windemere and Cranbrook sub-division rails while enroute to their final destination. The timetable specifies the following trains to run on these subdivisions:

KCS - Coquitlam to Cranbrook daily (Golden to Fort Steele)
KCN - Cranbrook to Coquitlam (Fort Steel to Golden)
979 - Lethbridge to Kingsgate daily (Sparwood to Fort Steele)
980 - Cranbrook to Alyth daily (Fort Steele to Sparwood)
984 - Cranbrook to Alyth daily (Fort Steele to Sparwood)

The symbol train operating rules and further information on type and handling are given in Reference 8. The significance of these symbol trains is that the schedules are condensed and are actually published and supplied to the customer. All such trains running to a schedule, symbol trains and unit coal trains, must give reasons for late placement from the given schedule.

All other service traffic is handled by way-freights. The only scheduled way-freights are operated on the Windemere sub. One way-freight is operated each way every day. These trains handle the Lake Windemere Gypsum mine traffic from Old Gypsum spur at Mile 68.9. Usual practice is to allocate a schedule from the time table for these trains such as No. 84, Fourth class Freight.

Thus it can be seen that this traffic is fairly minor compared with the vast tonnage moved by the prestigious unit-coal trains. One point of interest is that the Fording River sub-division was built during the 1960s specifically to exploit these coal operations. It can be seen from the CPR facilities map that there may be further extensions to this line to serve the proposed Elco mine. On the Cranbrook subdivision extensions may be made to serve the proposed mine at Sage Creek. The picture therefore is one of thriving activity and expansion which is rendering present facilities inadequate. It can be assumed that by the end of the decade this line will rival the West Coast mainline in terms of traffic handling and revenue.

7.4 Operating Procedures

Dispatching for the line is carried out from the CPR dispatch office located in Nelson, B.C. (Fig. 12). This office also controls train movements over the other subdivisions of the Kootenay division.

There are two principle methods of train operation on the line concerned: Train Order and Timetable and the Manual Block System. The Windemere and Cranbrook subdivisions use Train Orders and the secondary line to Fording uses MBS.

7.4.1 Train Order

Trains run on the basis of timetable schedules, or if they are extra, on the authority of train orders setting up schedules, a minimum of 20 minutes apart. In light-traffic territory where the actual spacing between trains is a matter of hours, there is little problem in most cases. However as traffic becomes more dense the fact that the time spacing is impaired every time a train unexpectedly slows down or stops places the whole burden of collision protection on the flagman, who at best is ill equipped to give adequate protection under bad weather conditions. Only at manned stations can the time interval be enforced; elsewhere there simply is no certain way by which an engine crew can tell how long ago the last train passed by until they encounter its flagman or unhappily its rear-end markers.

With respect to following movements:

a) Trains are to follow no closer than 20 minutes apart except in closing up at stations.

b) If a train slows down under circumstances in which it may be overtaken, Flagman throws off 5-minute red fusee.

c) If train stops, flagman is to go back a distance sufficient to stop any train following. When recalled by communicating signal, he leaves burning fusee and two torpedoes on track to protect train while he is returning and while train is resuming speed.

d) Train being overtaken must clear main track before scheduled leaving time of following train from last station in rear. In the event the train is delayed getting into clear, protection must be provided by flagman.

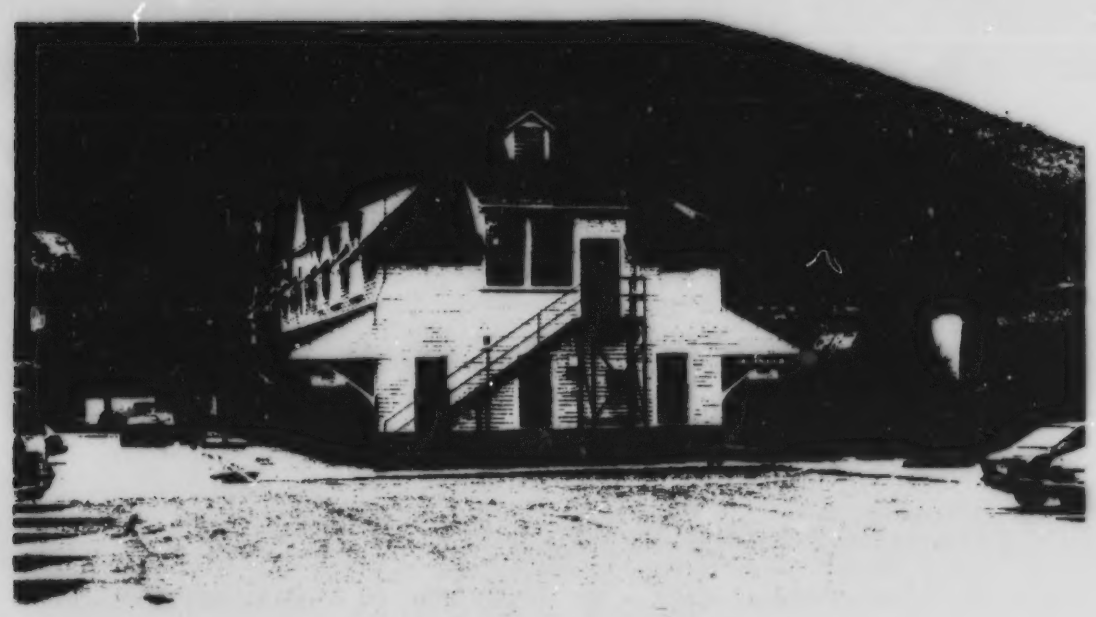


FIGURE 12 - CPR Station At Nelson, British Columbia

The top floor houses the dispatch centre for the entire Kootenay Division. Note the VHF point-to-train radio tower in the background.

With respect to opposing train movements:

e) Trains meet under complicated "superiority of trains" rules determining which train must take siding, clear other's time etc. In general, trains in one direction (designated by timetable) are superior to trains of the same class in the other direction.

f) First-class trains are superior to second class trains, etc; scheduled trains are superior to extra trains.

g) Train orders confer rights which have precedence over timetable superiority of class and direction. Orders are issued to authorise extra trains, change meeting points from those scheduled in timetable in case of delay, etc.

There are two standard forms of train-orders.

Form 19R - Orders may restrict the rights of a train at the point where delivered. They may have to be signed for by the train crew before being made complete and serving as a basis for permitting other train movements.

Form 19Y - Orders are of a nature which will not affect safety in the case of non-delivery, such as orders conferring additional rights to the train addressed. They may be picked up on the fly and need not be signed for.

Train-order signals are installed at remote offices to advise the train crew of train orders to be issued and their nature. These signals are of the upper quadrant semaphore type, with an arm for each direction of travel. The indications given are shown in Figure 13, and the pertinent rules are listed below:

402 - Train order signals affect all train movements in the direction in which the indications apply, the normal indication being proceed.

403 - When the STOP signal is displayed for trains in the direction in which the signal applies, it will indicate the delivery of restrictive train orders which may affect the train at the station and the train must stop before fouling the siding switch where an opposing train clears, except where the train order signal is beyond such switch, or where there is no siding, stop must be made before train passes the signal.

404 - When the caution signal is displayed for trains in the direction in which the signal applies, it will indicate the delivery of 19Y train orders, none of which is restrictive at that station. The speed must be so regulated as to enable proper delivery of the orders to both front and rear of the train.

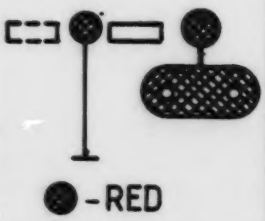
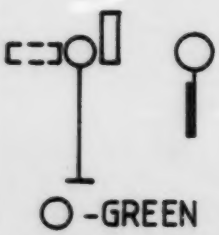
Rule	Signal	Name	Indication
401A		Stop Signal	Stop- for orders
401B		Caution Signal	Caution-for 19Y orders
401C		Clear Signal	Proceed- no orders

FIGURE 13 - Train Order Signal Indications (UCOR)

405 - When train orders or clearances are placed in a mechanical device for delivery to a train, additional train orders affecting that train must not be accepted by an operator until the train orders and clearances have been removed from the device and are in possession of the operator.

A few of the more general rules may be quoted:

(a) For movements requiring their use, train orders will be issued by authority and over the signature of the superintendent or designated train dispatchers and only contain information or instructions essential to such movements. They must be brief and clear; in the prescribed forms when applicable; and without erasure, altertion or interlineation.

Words or figures in train orders must not be surrounded by brackets, circles or other marks.

The different forms of train orders may be combined in one, provided that every movement in such combination directly affects the train first named in the order.

(b) Each train order must be given in the same words to all employees or trains addressed.

(c) Train orders, except those relating to track or other conditions, must be numbered consecutively each day, beginning at midnight.

Train orders relating to track or other conditions must be numbered consecutively, using a separate series of numbers, and re-issued if continuing in effect for a period of two weeks.

(d) Train orders must be addressed to those who are to execute or observe them, naming the place at which each is to receive his copy. Those for a train must be regarded as addressed to conductors, engineman, and also to pilots or snow plow foreman, if any. Those addressed to yardmasters may be used only by crews within yard limits. A copy for each employee addressed must be supplied by the operator.

Train orders addressed to operators restricting the movement of trains must be respected by conductors and enginemen the same as if addressed to them.

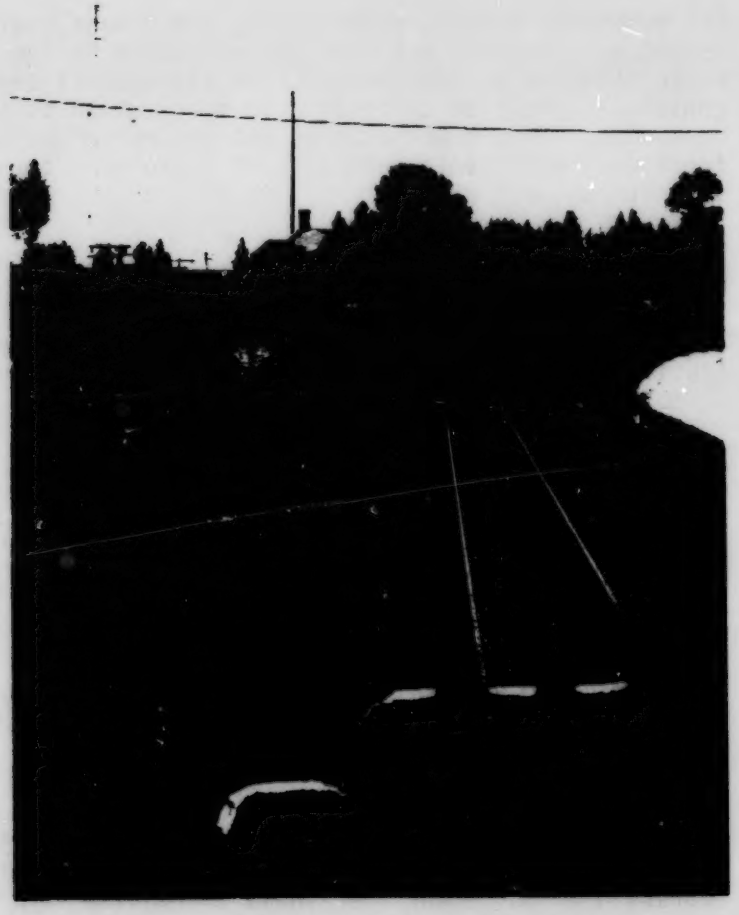


FIGURE 14 - Elko Train-Order Station On The Cranbrook Sub

Notice the operator by the train-order semaphore signal which is displaying proceed no orders to collect in accordance with UCOR rule 401C. Again the VHF tower can be seen behind the station.

(e) Each train order must be written in full in a book provided for the purpose in the office of the train dispatcher; and with it recorded the signals and responses transmitted, the offices from which the order is repeated and the time, the names of those who sign for the order, the times at which the order is made complete, and the dispatcher's initials. These records must be made at once and never from memory or memoranda.

(f) When train orders are transmitted by telephone, train dispatcher must write the order as he transmits it, and check and underscore each word and figure each time it is repeated. When transmitted by telegraph, he must write it as it is being repeated the first time and check and underscore each word and figure each time it is repeated thereafter.

The standard train-order form as prescribed by the uniform code of Operating Rules (UCOR) is shown in Figure 15.

Train-orders may be grouped into three principal classes:

(1) Those used for actually directing train movements, e.g., the meet, the pass, the right, the time, and the hold orders.

(2) Those used to designate the kind of train, e.g., the section, the extra, or the work extra orders.

(3) Those used to modify orders previously issued or to annul a previously issued schedule, e.g., the annulling and superceding orders.

As prescribed by the timetable at certain stations, a book known as a train register is provided upon which are recorded the time of arrival and departure of trains, the signals displayed, and other information such as engine number, number of cars etc. Train conductors are required to check the register for the arrival and departure of all superior trains which are due.

(Printed on yellow paper)

NAME OF RAILWAY

FORM 19 (R or Y)

Train Order No. 10

....., 19.....

To	At Station
Signatures	
	Repeated at Time Made Com Time time Opr Jones

FIGURE 15 - Train Order Form (Form 19)

FIGURE 16 - Train Order Meet at Morrissey on the Cranbrook Sub, Between Extra 5816 West, a Loaded Unit Coal Train, and a Returning Empty Unit Coal Train.

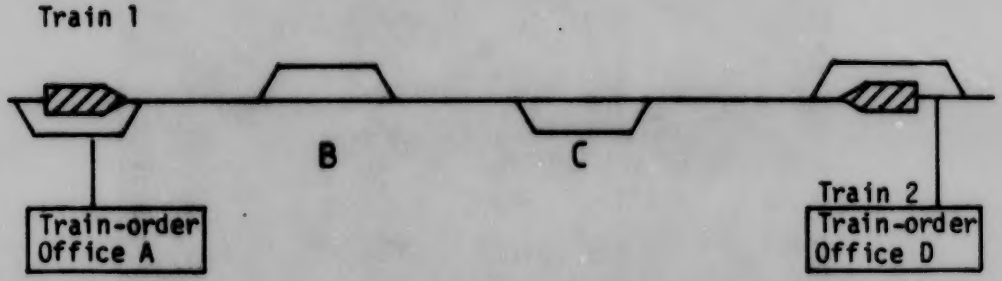
NOTE: The empty train is in the siding despite the fact that it is running in the superior direction. Also notice trainman from standing train in position on ground so as to check passing train for dragging equipment, etc. as per UCOR rule 111. Also note the empty train is carrying two green flags and two green lights according to UCOR rule 20 to indicate a section following.

The train order offices for the Sparwood to Golden section of line are located at:

Sparwood (RD)	- Register station
Elko (KO)	-
Fort Steele (FS)	- Register station
Skookumchuck (SK)	- Register station (originating trains only)
Windemere (AR)	-
Spillimacheen (MA)	-
Golden (GD)	- Register station

The positioning and number of these operators and train-order offices is of major importance in the traffic capacity and efficiency of the line. Obviously the closer spaced the operators are the more control the dispatcher has over train movements. However, the economics of supplying these operators means in practice that their number is kept to a minimum.

The primary problem encountered thus in train-order operations are delays caused by bad order planning which cannot be corrected between train-order offices and to an even greater extent by unforeseen situations arising. Consider the scenario given below.



No 2 Eng 402
Meet No 1 Eng 401 at B
No 1 take siding at B

Train order issued to both trains

If train 2 having set off from D experiences mechanical failure at C, train 1 will arrive at B and hold the siding in anticipation of No 2's arrival. In this situation a taxi would have to be sent out to train No 1 at B and the conductor brought back to the train-order office. New orders would then be issued rearranging the meet at C and thus allowing No 1 to continue on its way. The problems of this type are numerous and cause delays which drastically reduce the number of trains that can be run on a section of line.

However, the major shortcomings of the train-order system are associated with protection against rear end collisions provided by flagging, the failure of which is notorious. It fails both from the negligence of the flagman to carry out or display the signal, and of engineman to heed it when given. On a single track line like Fording to Golden the men in charge of trains have the additional burden of considering their rights as against trains coming from the opposite direction, which are of two or more different classes. Furthermore the superiority of such opposing trains may vary from hour to hour, or may be varied by train-orders from the dispatcher at any stage of the train's journey. Head-end collisions due to confusion over these rules and from mistakes in reading the timetable, wrong train-orders or non-delivery of orders, to forgetting orders and other errors, are as notorious as are rear collisions from flagging failures.

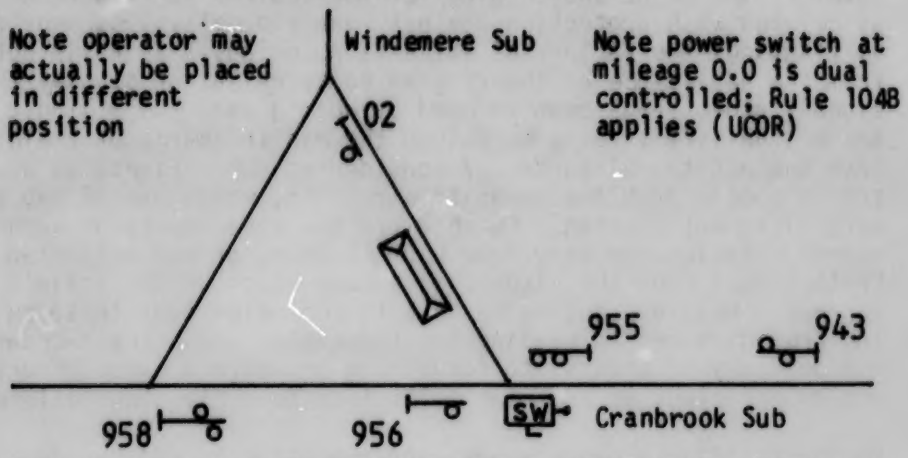
On the positive side, however, where traffic is relatively light and the territory fairly easy to operate (low gradients-slight curves) the system can work well, especially given the experience of well versed train-order dispatchers. The system also has the advantage that operations can be scheduled well ahead of time, allowing the dispatcher time to make changes at a later time if operations are not running according to plan. It may be, however, that dispatchers like this plan ahead feature, because it gives them time to put their feet up after the initial planning has been done.

On the Windemere sub-division train-order operations seem to work reasonably well, partly because of the fairly level straight route along the Columbia valley. This route allows trains to run according to schedule without too many problems. Furthermore with three intermediate T.O. offices the operating plan can be altered relatively easily.

In contrast the Cranbrook subdivision presents quite a different picture. The gradients are higher, the curves sharper and the traffic more dense, with only one intermediate T.O. office in 55% of Windemere sub's length, operations prove more difficult to control.

An interesting point about movements between the Windemere and Cranbrook subs is that they are governed by a local interlocking at Fort Steele. This provides colour light signal indications to trains approaching the junction and power switch operation allows remote lining of the route for the train. As Fort Steele is a crew change point trains will generally be stopped if proceeding on to Golden to allow for crew changeover.

The layout of the junction is shown below:



Note signals designated in decimiles relative to subdivision; numbering is even for one direction and odd for the other in accordance with standard practice.

7.4.2 Manual Block System (MBS)

In the manual block system trains are kept apart by a space - interval system in which at any given time a train has exclusive possession of a section or "block" of track. Compared to train-orders this is a more enforceable idea because the space cushion protecting a train does not diminish and then disappear if the train falls behind schedule. As soon as the telegraph became available so that an operator could be advised whether or not a preceding train had passed the next station, the manual block system became possible and developed rapidly.

The general features of traditional MBS are given below:

1) Block signalling supplements but does not replace timetable and train-order operation. In single track territory permissive blocking is in effect only for following movements.

2) Under permissive manual block rules, trains other than passenger may enter block occupied by preceding train other than passenger under permissive aspect, train order, or caution card.

3) Interlocking towers also act as block stations: length of block is from one station to next, usually 5 to 15 miles. When block office is not open, block becomes distance between next open offices or else signals are left at stop and train crews receive orders by telephone.

4) Operator at each block station keeps log of all trains passing into and out of blocks adjoining his station, from which clear or occupied condition of block can be determined at all times. He must check with operator at leaving end of block before admitting train; signal is kept at stop except upon approach of train.

5) Trains must approach all block stations prepared to stop, since each block signal indicates condition of occupancy of next block only.

6) To provide some stopping distance the operator will not report block clear until markers of train have passed a specified distance (usually 300 ft.) beyond signal at leaving end of block.

7) Once train has left block, it must not back into it again until operator has regained control of the block by contact with operator at entering end.

Since flag protection is still required by rules should a train stop or slow down, a longer succession of human errors is required before a rear-end collision can result and the operator can at least display his warning signal promptly and effectively without having to slog through sand, sleet, or snow. Manual block is primarily a safety rather than a capacity-increasing or economy feature. It is for one thing a "one block" system in which the signal indication gives no information about the second block ahead. As a result, unless distant signals are provided, train speeds are limited by signal-sighting distances when approaching block offices.

The big enemy of track capacity is block length, usually the distance between stations, a matter of 5 to 15 miles. From the time even a fast train enters a block, a lot of railroad is tied up until it emerges. One assist comes in the use of permissive blocking in which a freight train following another freight is permitted to enter and proceed through an occupied block, moving at restricted speed prepared to stop short of a train or obstruction but not to exceed 15 miles an hour. If passenger trains are involved, a flagman must precede the train through the occupied block. In either case with such long blocks much time can be lost.

It should be noted that while this method of MBS operation has never been adopted by CPR the underlying principles apply to the radio MBS system used between Fording and Sparwood.

The system at present used by CPR under the term MBS is not based on wayside signals but rather on direct dispatcher to train radio communication. This has the advantage that no remote operators are required or for that matter expensive wayside equipment.

The system was originally only used on the Vancouver Island subdivision of CPR's Pacific Region. However, with the introduction of Timetable No. 94 in April 25, 1982 the following subdivisions were now specified as MBS operation:

Kimberley sub
Cranbrook sub (Crowsnest to Sparwood only)
Fording River sub
Nelson sub
Kingsgate sub
Boundary sub
Rossland sub
Slocan sub
Kaslo sub

From comparison of Timetables No 93 (before MBS) and No 94 it can be seen that the introduction of this system facilitated the closure of four train order offices.

Manual block clearances are set up by the dispatcher on the prescribed form; protection against conflicting moves is provided by the dispatcher's record of clearances issued. The MBS clearances are transmitted over voice radio direct to the relevant trains engineman and conductor. The specific working of the system is loosely defined by rules 321 to 323 of the UCOR:

Manual Block System Rules

321 - On portions of the railway so specified in the time table, or by special instructions, the use of the main track will be governed by the manual block system.

322 - The movement of trains will, unless otherwise provided, be supervised by the train dispatcher who will issue instructions as may be required to operators or conductors.

323 - Special instructions as may be necessary to govern this method of operation will be issued. Except as affected by such instructions and Rules 321 and 322, all Operating, ABS and Interlocking Rules remain in force.

It can be seen that these rules refer to a set of special instructions which in the case of CPR are issued with the timetable. These are reproduced in Appendix H and describe in detail the operation of the system.

It can be seen that this form of MBS system is somewhat different to its conventional counterpart. While the basic premise of giving a unique block to a train still holds, variations in rules allow scheduling that is more akin to train orders than traditional MBS. In fact the system may be viewed as a system that allows direct delivery by radio of train orders to the train crew. However, the implications on safety of doing this can be judged by the fact that only light traffic subdivision are operated under MBS.

The MBS system does not allow for arranging authorities for closely following movements. Furthermore the facilities for recording block occupancy are relatively unrefined and place safety directly in the hands of the dispatcher.

Records of MBS clearances are made on the train-sheet in the following manner.

Crew	SMITH / JONES	
Train	657 01	
Addn info loads, empties, etc.		
Crowsnest Fabro Michel Natal Sparwood Olson Hosmer Fernie Morrissey Elko	304 S	MBS Clearance No. Note blanking ensures MBS clearance does not infringe on T.O. territory

Note MBS clearance forms are shown in Appendix H

Thus safety of movement is effectively interlocked in the dispatcher's brain with the aid of the MBS record as above. Unlike T.O.'s there are no remote operators to check clearances; they go direct to the train crew. As this system is relatively new it may be that more effective methods of ensuring safety may be devised before too long.

Obviously with MBS there is more flexibility in making changes to authorities as direct radio communication can be used. The radio is also used to OS trains at specified points to determine their positions. This procedure is again subject to errors that cannot be checked by remote operators. In using the system an excessive amount of time is spent repeating messages over the radio link and preparing the required documentation. It will be seen later that audio communication is the most frequent task in dispatching. MBS places further emphasis on this task.

Generally speaking the MBS system is not liked by either the dispatchers or train crews and their comments are aptly summed up by the following quote: "MBS is a cheap system for controlling train movements - if a dispatcher makes a mistake it's a simple task to fire him and get a replacement". This of course refers to the fact that the dispatcher has far more responsibility for safety with MBS than the train-order system. However, one facet of MBS is liked and that is the flexibility of direct radio dispatch and the variable lengths of the block authorities.

7.4.3 Train Operation

Freight train handling involves the coordination of many factors which command attention, obedience to the local operating rules, and the exercise of good judgement.

The initial task is to check out locomotives to ensure that they are properly conditioned for service. These checks are made in the following areas:

- External Ground Inspection
- Engineroom Inspection
- Cab Inspection on Lead Unit
- Trailing Unit Cab Inspection

With the advent of general purpose and special duty road switching locomotives, operating characteristics and design accomodated a wide variety of services. To increase flexibility and utilization such units were called upon to perform in multiple with other model locomotives and other air brake systems.

There are three types of multiple unit (MU) control available with the No 26L brake system

a) The 2-pipe system
b) The 1-pipe system
c) The universal system

Single pipe 26L or universal 26 L equipped locomotives all have MU-2A valves.

Preparation of a train for road movement entails at present a procedure which consists of checks on couplings, brake pipes, and angle-cock settings. Following these checks the train air brake system is charged to the normal brake pipe pressure, either from the road locomotive or from the yard compressed air supply. Train brake tests are performed before the train is started.

Starting the train must be carried out with great care to ensure that excessively high forces are not exerted on the draw-bar. The diesel-electric locomotive is capable of exerting high steady starting tractive effort. This tractive effort is equal to approximately a quarter of the locomotive weight. Multiple unit consists can produce excessively high total tractive forces if care is not exercised in their use by the engineman. For example, a 4-unit consist of 190 ton diesel-electrics can produce in the region of 360,000 lbs pull on the train. Fortunately unit coal trains are fitted with couplings/draft gear that can withstand these high forces.

It has to be ensured that a long enough delay has been exercised to ensure brakes are released on all cars before attempting to start. Power is applied slowly and steadily and the loadmeter (see Fig. 18) monitored according to the approximate figures given below for a six axle/motor unit.

Loadmeter (amps)	Tractive effort (lb)	
400	22800	For 0-10 mph
600	39600	62:15 gearing
800	57600	full field
1000	77500	
1200	97200	
1400	117500	

Slack or 'play' between cars is present to a greater or lesser degree. Free slack or the free motion between two adjoining couplers can be as much as 1 inch.

The conventional draft gear, to which couplers are attached, act to absorb shock and impact. However, they have from 2-3 inches of movement built in. Therefore, there is a sizeable movement possible within a train between the front and rear ends. Typically the following slack is found.

Train Length	Free Slack	Draft Gear Movement	Total for Train
50 cars	50 in.	250 in.	25 ft.
100 cars	100 in.	500 in.	50 ft.
150 cars	150 in.	750 in.	75 ft.

Slack is a benefit in starting a train because it can allow cars to start individually, rather than all together. The locomotive speed must be kept low and constant until the rear of the train is in motion. If the locomotive is allowed to accelerate too rapidly, the standing cars in the train will be "jerked" from 0 to 4 mph. This "jerk" action may easily exceed the strength of draft-gear and couplers. Brakes applied on the rear cars can make this situation more serious.

Certain ascending grade starting situations require special care in gathering slack, and under these conditions radio communications between the locomotive and caboose is extremely useful. On curves, good judgement is needed to apply power gradually. High starting tractive effort may pull a lightly loaded car off the track or out of the train, especially if the curvature is sharp. If an upgrade is involved, the situation can be more serious.

To summarise the most important factors in train handling:

- knowledge of railroad
- knowledge of where train is located on the railroad
- ensuring a proper brake release is obtained
- knowledge of where the train slack is and ability to adjust
- correct slack handling
- smooth power applications, one notch at a time
- load indicator monitoring

During the time that the train is accelerating the power must be worked steadily, avoiding quick throttle changes which can create snap or whip action in the train.

As speed increases beyond the starting rail adhesion limit, the tractive effort reduces in proportion to the increase of speed. Each throttle step is in reality a specific horsepower position. For the SD40 locomotive of 3000 HP: -

Throttle					
	IDLE	-			
	RUN1	- 200 HP	RUN5	-	1420 HP
	RUN2	- 390 HP	RUN6	-	1830 HP
	RUN3	- 710 HP	RUN7	-	2375 HP
	RUN4	- 1085 HP	RUN8	-	3000 HP

However, the train resistance increases steadily as the train speed increases. When the horsepower output of the locomotive equals the resistance horsepower of the train a power/speed balance is reached. As the desired speed is approached the throttle is reduced gradually until speed balances or holds steady. Care must be exercised to avoid unnecessary "drifting". The locomotive may "back into the train" while drifting, which will tend to cause slack to bunch. This may not be sensed on the locomotive, and when power is reapplied a jerk may be experienced which may damage equipment.

To summarize over the road operation:

- Plan all movements in advance to control train speed and slack.
- Never allow the train to 'control the engineman'.

Decelerating the train is a complex procedure depending on type of train, distance available, and gradient. Where sufficient distance is available speed reductions can be made by simply letting the train slow down due to its inherent resistance. The throttle must be slowly and gradually reduced to give the train slack time to adjust itself without surges and shocks. The brakes must not be applied too hard, otherwise slack run-in and shock can be extremely severe.

Primarily the engineman should know the characteristics of the railroad and equipment in the train such as train length, number and position of loads and empties, tonnage etc. This knowledge will assist him in proper use of power and brakes to adjust and control speed and slack.

The dynamic brake can often be used to advantage in slowdown and stops. With multiple unit operation it is possible to create sufficient retarding force with the dynamic brake to cause extremely high compressive force in the train. When handling a tonnage train on a descending grade where the dynamic brake will not properly control speed of the train, the air brake should be used to an extent which will allow the dynamic brake to be reduced to a value where it will be flexible enough to control the changes made in speed due to physical characteristics of the road. Where practical it is important to plan the movement well in advance to avoid maximum dynamic brake while head-end cars are passing through a crossover, or turnout or around sharp curves.

The SD40 locomotives used on Fording - Golden unit trains have cabs with the general layout given in Figure 17.

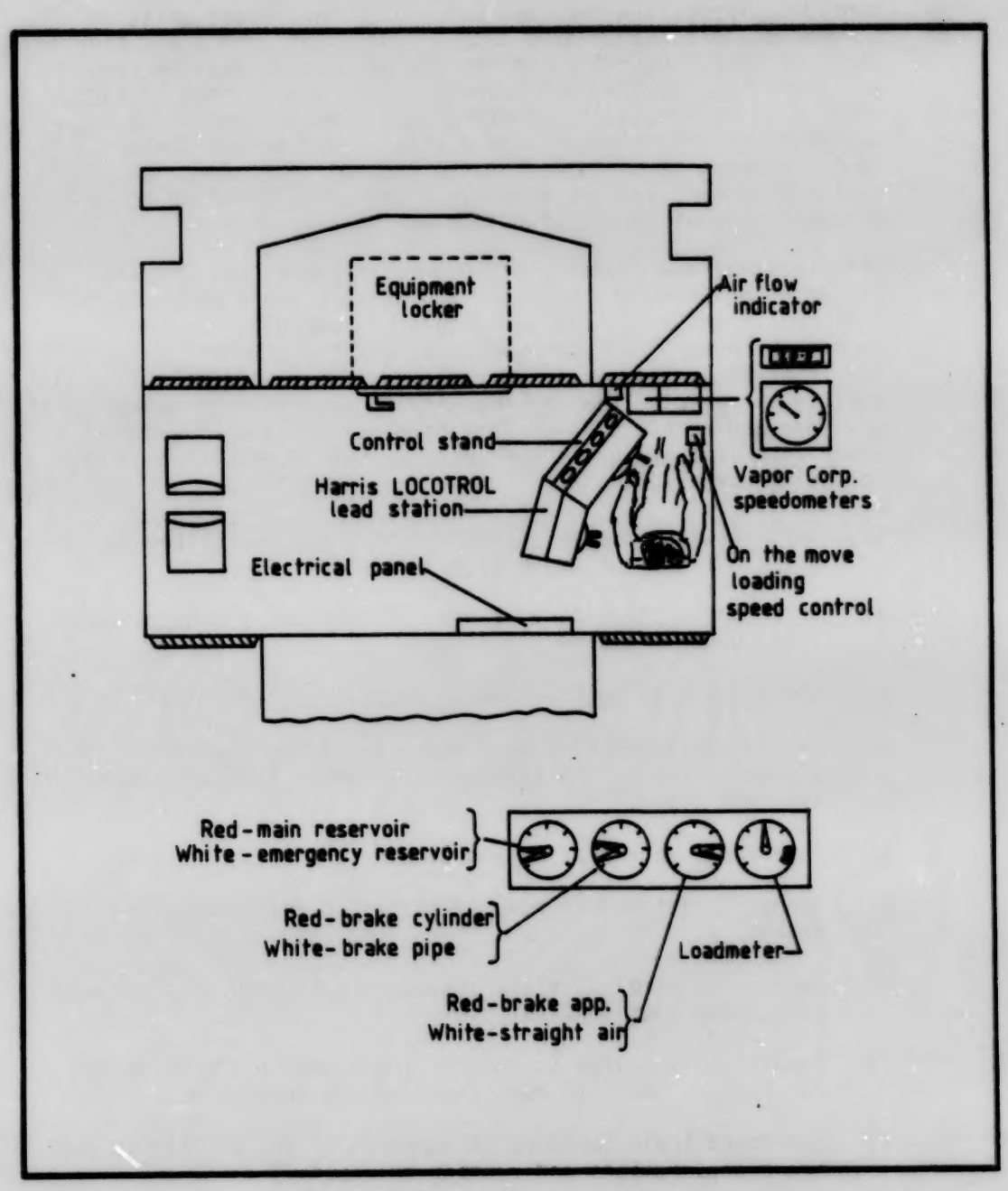


FIGURE 17 - SD40 Cab General Layout

The Harris Locotrol system is designed to provide synchronous automatic control of a unit or section of units (consist) located at some point along the train and used in addition to the lead consist. The system provides control of the remote units by command signals transmitted over a radio link from a position in the lead unit. Operation of the system is such that trains equipped with locotrol can operate within radio range of each other with no danger of interference to one another. The equipment is comprised of a lead station and remote station. The lead equipment is installed in the locomotive to function as the controlling unit and the remote equipment is installed in an unpowered 'robot car' to function as the remote unit.

With Locotrol the division of locomotive power, that is the placement of units at the front and at some other point in the train build-up, makes available the full potential of the locomotive power. The principles of digital control employed in the Locotrol system utilising radio equipment as a telemetry link provide the precise timing necessary for coordinated operation of the lead and remote units. This permits division of locomotive power into separate units operating in unison resulting in the following advantages:

a) Initial charging time of the train air brake system is one-fifth that of conventional charging.

b) Brake application time is one-half that of a conventional train under the same conditions.

c) Air brake release time can be reduced by two-thirds.

d) Increased power efficiency and overall tonnage capabilities are enhanced through synchronous control of diesel power of two consists.

e) More rapid acceleration and deceleration of the train.

f) Stopping distance is reduced by faster application of brakes.

g) Improved control of slack action, greatly reducing damage to cars, couplings and lading.

h) Enables long trains to achieve and maintain higher speeds for faster, smoother runs and improved scheduling.

i) Low speed train handling is improved by the ability to make brake applications and running releases.

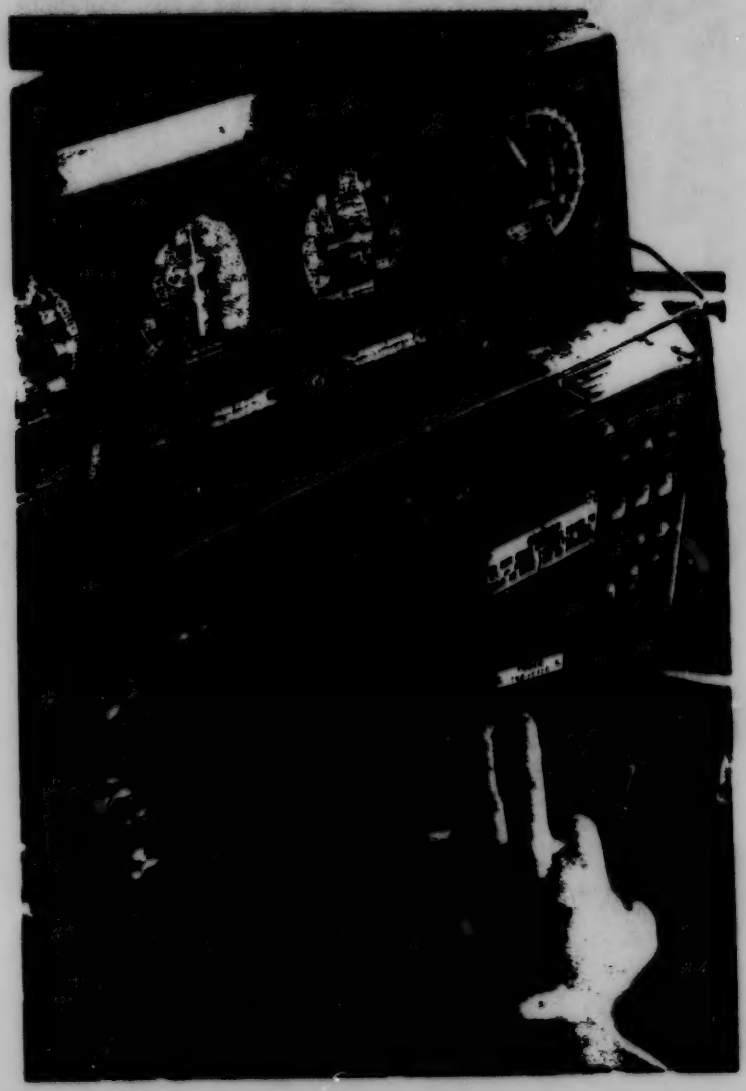


FIGURE 18 - Control Stand Of SD40 Unit No. 5816
Used On Unit Coal Train Operations

Note on top of the stand gauges for 1) main reservoir/emergency reservoir air pressure, 2) brake cylinder/brake pipe air pressure, 3) brake pipe flow indicator, 4) loadmeter. Also visible are the controls for the dynamic brake, throttle and reverser. It is interesting to note that dynamic braking is being applied and the grid current is 300 Amps.

FIGURE 19 - Another View Of The SD40 Cab Showing The Analogue And Digital Speedometers Supplied By The Vapor Corporation

Note the deep shroud on the digital readout unit and its high location.

The Vapor TOR II equipment fitted to master control SD40 locomotives is a train operations recording system. Basically the system records on magnetic tape the various locomotive running parameters for a given trip. Typically these parameters include throttle settings, brake settings, dynamic brake settings and train speeds etc. The recordings are keyed to the subdivision mileage by Digitrac transponders at the following locations:

- Sparwood
- Colvalli
- Horse Creek

Once calibrated, the system's running odometer maintains the relative sub-division mileage. The system is used to analyze the efficiency of the unit-train operations.

While conducting the site study the opportunity of riding a unit train between Sparwood and Fort Steele was taken.

The train was the Extra 5816 West, 3rd June 1982.
803 - Sparwood to Roberts Bank
Consist - 2 SD40 (GRF30) head end
2 SD40 (GRF30) mid-train
Loads - 108
Empties - Nil
Gross trailing load 14,500 tons

Train-orders were delivered at Sparwood, a bundle of about a dozen separate orders relating to the schedule, and slow orders, etc.

The maximum speed for the Cranbrook sub-division is 30 MPH, this figure being the direct result of government imposed restrictions. General consensus amongst crews was that the speed limit could quite safely be raised to 40 MPH.

As the train left Sparwood it became obvious that the ride was relatively smooth and the vibration level only moderate. Even on full power the noise level was not that high.

While on over the road operation speeds are limited by line of sight stopping distances at certain points. Also the crew have to be aware that there may be a rear flagman providing protection for a train ahead just around the next corner. The stopping distance for a unit train of this type with a full service brake application (approx. 22 PSI reduction) from 30 MPH is in the order of 3500 ft. Actual braking test data on a similar unit-train of 100 cars are given in the graph on the following page.

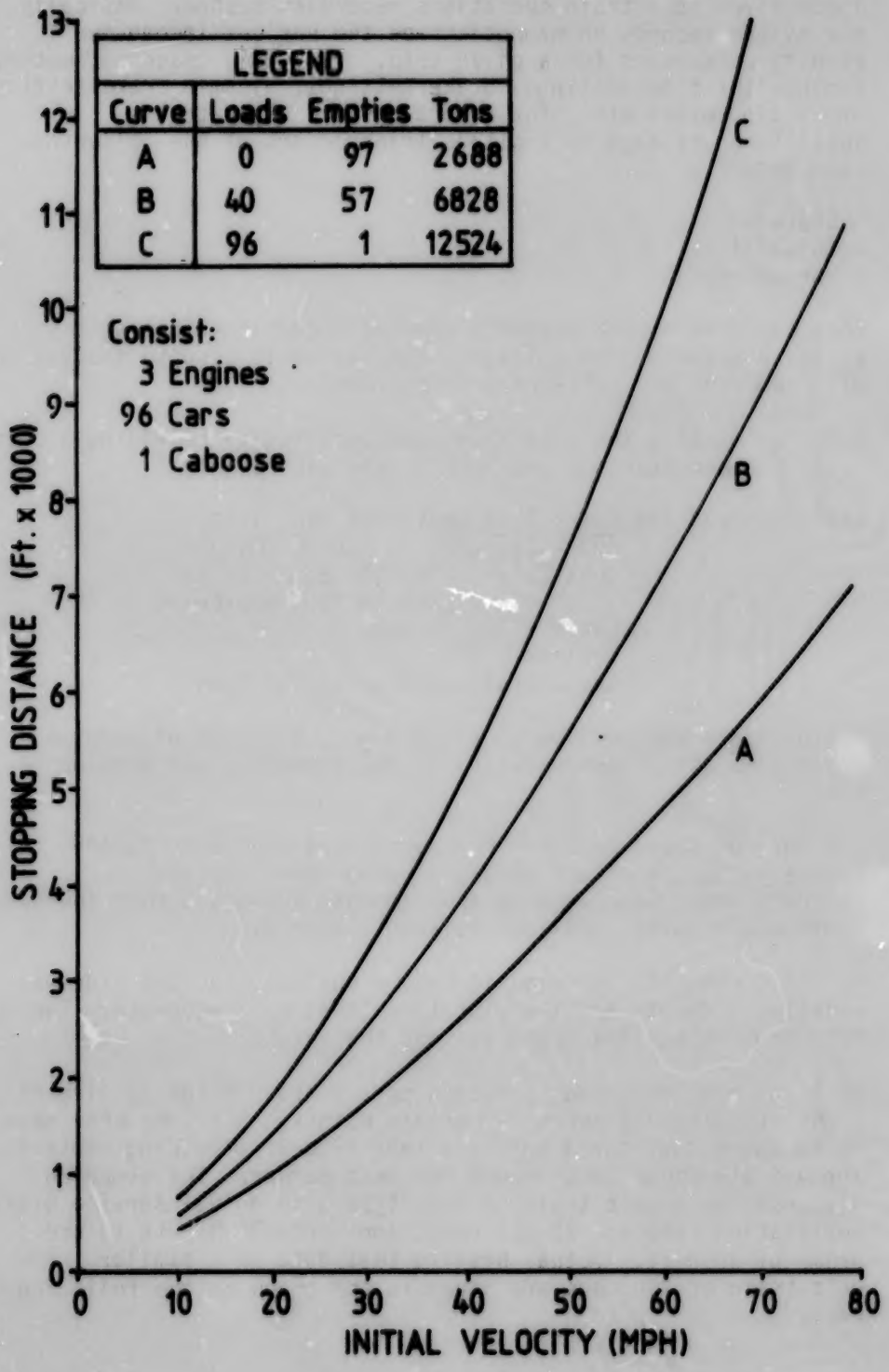
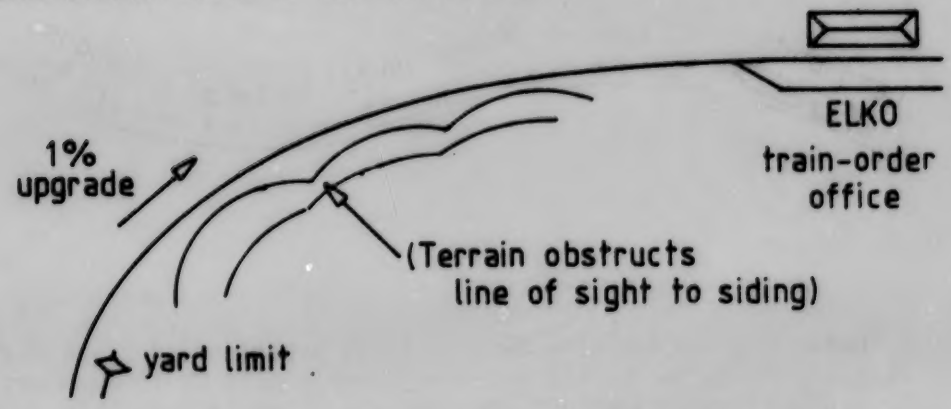


FIGURE 20 - Stopping Distance Versus Initial Velocity For A 100-Car Train

It seems that one of the biggest problems is not having a signal system that tells the enginemen the status of track ahead of him. One particular example of this was seen on our way into Elko station which is laid out as shown.

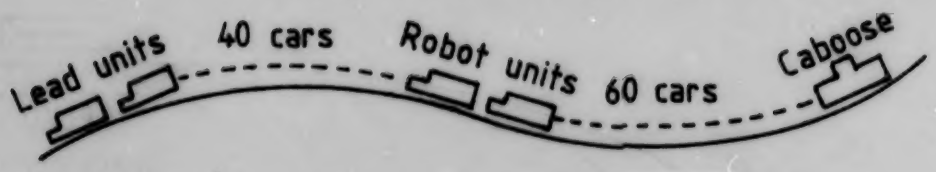


Rule 93 of UCOR states that, third class, fourth class, extra trains and engines must move within yard limits at restricted speed unless the main track is known to be clear.

As the train was of fourth class it should have slowed to 15 mph or less at the yard limit sign. However, the approach is on a 1% upgrade which requires full power and thus more than 15 mph just to reach the summit. Thus the train may round the corner and find a unit switching just in front of it. Obviously the installation of CTC would alleviate this problem through the use of an approach signal at yard limits or thereabouts.

The train made three meets during the trip but with right conferred on it by train-order it had a clear run (see Fig. 16). The trains met were a scheduled unit train of empties, a scheduled way freight, and an extra ballast train. As a result of our right the train didn't have to stop until it reached Fort Steele where crews are changed. However, the scheduled train of empties had a 1 1/2 hour wait at Morrissey for our train and two sections following to clear.

Train handling was extremely precise, the engineman using great skill and knowledge of the subdivision to control the train with power and dynamic brake settings. In fact he knew to the nearest mph what speed the train should be doing at every point along the route. He was very adept at letting the train coast through long sections without any power notched on. At several times along the route the head and mid-train robots were in different atitudes with respect to gradients. The situation below shows a typical case.



Under a situation like this it takes experience to know when the train should be braked and when power should be independently applied to or taken off the robots. It would seem that such complicated decisions will preclude the inclusion of any useful dynamics in the LIC system. It is hard to believe that LIC could match the efficiency of the engineman in these matters under any conditions. The crew said at present train separations were not uncommon.

During the trip the tail-end crew use radio to report the train position to closely following trains or sections. Note though this does not mean that flag protection according to Rule 99 is not required if the train makes an unscheduled stop.

Talking to the train crews and road foremen the following suggestions were proferred:

- Power switches are seen as an absolutely essential feature of a system on these subs; without them they may as well stick to the train order system.

- An updated speed limit display in the cab was seen as a very useful feature and one that CTC cannot provide.

- The provision of any system must cut down on the number of crews by reducing running times.

7.5 Communications

At present voice communications on the Fording to Golden line of CPR are carried over a variety of media. In keeping with standard practice on CP Rail all trains are equipped with direct point-to-train radio operating in the VHF (160 MHz) band.

However, there has been general reluctance to use this radio system for safety related messages governing the movement of trains. Thus train orders are still normally passed by telephone to a station agent, typed out manually, and handed to the crews of passing trains - despite the fact that the dispatcher can talk directly to the engineman.

Radio is not trusted as a medium for transmitting train orders because the risk of the order being misdirected or misinterpreted is too great. However, the MBS system now being implemented does allow transmission of movement authorities over the radio but possibly at the expense of safety. In addition this system is only operated on light-traffic lines where transmission requirements are less demanding.

At present the territory between Fording and Sparwood is covered by a manual block system with direct radio communication between train dispatcher and train. Coverage is provided by two VHF towers located at Fording Mountain and Sparwood respectively. Communications between these sites is provided by a point-to-point UHF (450 MHz) light route radio system. The remote site at Fording Mountain is powered by a solar energy and battery back-up system.

The territory between Sparwood and Golden is covered by timetable and train orders with a dispatchers telephone circuit between open stations. These circuits are leased four-wire circuits supplied by the local common carrier (B.C. Tel) and serve the following locations:

- Sparwood
- Elko
- Fort Steele
- Skookumchuck
- Windemere
- Spillimacheen
- Golden

These sites are also coincident with the VHF point-to-train radio towers which utilize leased lines to connect through to the dispatch office.

These communications facilities are carried between Fort Steele and the dispatch office at Nelson on leased channels of a microwave point to point link.

Propagation tests have been carried out on all of the subdivisions concerned and have not highlighted any serious black areas. However, general opinion amongst CP Rail staff, particularly dispatchers, is that the present coverage is not good enough for efficient dispatching. With the MBS system relying on direct dispatcher to train radio-communication, the implications of poor coverage are more serious than in train-order territory. The Canadian Transport Commission have been active in testing radio coverage on all MBS operated lines in the Kootenay division of CPR. The tests being carried out using radio equipment mounted in a Hi-rail car ensure coverage is good enough for train safety to be maintained.

CP Rail have signified their intent to improve radio communications in this area and its seems inevitable that a conventional microwave system will be installed in the near future. It certainly seems that the present facilities would be totally inadequate for the purposes of implementing a LIC system. Any communications system installed between Fording and Golden will have far reaching implications on the practicality of a LIC implementation on this line. The following factors will be of prime importance.

- Repeater site locations
- Trunk route
- Local topography
- Radio coverage provided
- Channel availability

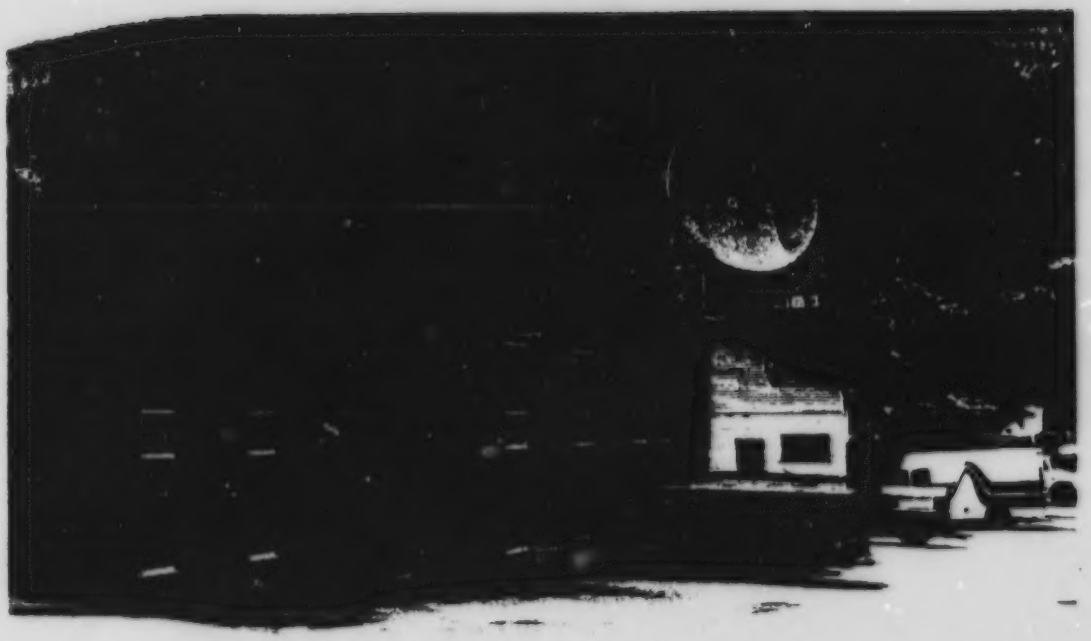


FIGURE 21 - Canadian Pacific Telecommunications Building Adjacent To CPR Station At Nelson

Notice the microwave antenna that is part of the system relaying information to trains and operators on the Fording to Golden Line.

7.6 Dispatcher Functions

7.6.1 Dispatcher Tasks

The tasks carried out by a dispatcher in controlling train movements may be simplified to the following categories of functions.

Prepare Documentation

a) Train order book detail

Written in full in a dedicated book. The order, the names of those who have signed for it, the time, the responses which indicate when and from what office the order was repeated, and the train dispatchers initials are entered.

b) Train sheet detail

Train time sequences are entered in the same manner as trains shown on timetables. Movement of Hi-rail vehicles shown in pencil so that they may later be erased. The train dispatcher must record the time of train arrival and departure; the number of loaded and empty cars and the tonnage; the names of conductors, engineers, and other crews at terminals; and the time such crews are relieved from duty. Also he must record delays, weather reports and unusual occurrences such as derailments, fires, or accidents. Before issuing running orders to an extra, or work orders to a work extra, he must record all such train data and protect movements against opposing extra trains by train orders.

c) Transfer book detail

Relieved dispatcher must transfer all outstanding train orders to the transfer book, identifying each by number. The relieving dispatcher must read and understand before signing the transfer. Before commencing operations he must be familiar with T.O.'s, lineups, track permits and train locations.

Note: - Book keeping constitutes about 40% of total task time.

Conduct Preliminary Planning

Initial preliminary planning is done before assuming responsibility for the operating position (change of shift); it then becomes an ongoing response to traffic conditions. Preliminary planning is a prerequisite to an efficient control operation. Included in this function is the review of all documentation which has bearing on the operation, equipment check, traffic condition/status, and familiarization with and/or determination of routes and schedules along with the necessary co-ordination.

Monitor/coordinate train movements

Major function with tasks which are less demanding, less critical, and of lower priority. The Dispatcher uses the CTC panel and radio/tel communications for progress reports and co-ordination.

Initiate/Stop train movements

Primary function: operation of radio for issuance of train orders and those aspects of control which are positive and self-initiated. It does not include activities which are responsive, passive, or administrative.

Respond to unplanned events

Unplanned events may necesitate considerable replanning and rescheduling of actions. Preoccupation with a particular unplanned event may delay execution of scheduled/planned events and possibly affect accuracy and validity of input-output information.

Respond to emergencies

a) Differentation between "unplanned events" and "emergencies" is by the apparent level of immediate danger or threat to life and/or property involved. Events which were originally classified as "unplanned" can suddenly develop into emergencies. The important consideration is the effect if action is not taken immediately to safeguard life and property.

b) Blazing hot-boxes

Once the dispatcher is aware of a hot-box, immediate action must be taken to determine the extent of the condition, i.e., blazing (cotton wastefire) or not. Resolution must take into account traffic situation, availability of sidings and support, and supervisory wishes.

7.6.2 Distribution of Activities

To identify the frequency of occurrence of the various dispatcher tasks, an analytical matrix format was used to describe the total number of tasks for a given period.

Certain tasks require very little time, effort and attention. Others, because of their complexity, require prolonged effort and great concentration; therefore, a dispatcher may spend more time on tasks that occur less frequently. One must consider the nature of the various functions as previously described, to properly evaluate the dispatcher performance reflected in Table 5.2

The data were obtained by maintaining a detailed log over a two day period of a train dispatcher's activities (data supplied by American Train Dispatchers Association). In order to restrict the data to limits enabling the development of conclusions, the listing of activities was deliberately limited, with many sub-tasks grouped together.

Subsection 7.6.3 identifies and explains the content of each task.

Task	Dispatcher Activity	Percentage of Total Tasks		
1.	Perform documentary entries	8.85	9.34	9.81
2.	Review guidance documentation	2.21	2.05	1.89
3.	Coordinate operations information (internal)	2.83	2.41	2.01
4.	Coordinate operations information (external)	9.37	8.55	7.80
5.	Determine equipment status	2.21	2.71	3.19
6.	Establish routing	1.84	2.34	2.84
7.	Establish scheduling	4.42	4.76	5.08
8.	Receive traffic advisories	0.25	0.96	1.65
9.	Monitor/initiate audio comm.	17.07	15.30	13.59
10.	Issue traffic advisories	0.37	1.02	1.65
11.	Initiate system control actions	10.44	9.82	9.22
12.	Issue/Annul train orders	1.59	1.63	1.65
13.	Issue Hi-rail operations permits	5.04	4.94	4.85
14.	Receive/Relay weather advisories	0.49	0.60	0.71
15.	Experience communications problems	4.05	2.77	1.54
16.	Respond to internal equipment failures	0.12	0.24	0.35
17.	Respond to external equipment failures	0.98	1.08	1.18
18.	Respond to unplanned events	3.31	3.73	4.14
19.	Respond to emergency conditions	0	1.20	2.36
20.	Transmit train clearances	0.85	1.14	1.42
21.	Receive clearance/permit requests	2.33	2.53	2.72
22.	Receive/transmit train position requests	8.85	8.31	7.80
23.	Perform equipment adjustments	0.61	0.60	0.59
24.	Receive/transmit information requests	8.47	7.65	6.86
25.	Conduct business outside work area	1.11	1.20	1.30
26.	Coordinate work crew requirements	1.84	2.71	3.55
27.	Non-operational absences	0.49	0.36	0.24
		DAY 1		DAY 2
	Total Tasks	814		846

TABLE 1 - Train Dispatcher Activity Task Distribution

Because of the limited sampling the data do not provide a statistically sound basis for generalization on frequency of occurrence of various activities. They do illustrate, however, the variety of matters to which a train dispatcher must attend almost continually every day and the way in which the functions analyzed individually intermingle, overlap, and combine.

7.7.3 Definition of Dispatcher Tasks

Perform documentary entries: Includes all data entries, notations, checks, etc. performed on the following documents:

a) Dispatchers Train sheet
b) Train order book
c) Work order book
d) Transfer book
e) Personal notes
f) Other report requirements

Review guidance documentation: Visual review of information pertinent to dispatcher activity, e.g.; bulletins, directives, memos, messages, notices, personal notes, etc.

Coordinate operations information (internal): Any transfer, exchange, or dissemination of information, instructions or requirements between the dispatcher and other dispatchers, operators, chief dispatchers etc., within the general internal confines of the overall dispatch operation.

Coordinate operations information (external): Includes the interchange of ideas, information and situation occurrences between the dispatcher and operators, signalmen, trackmasters etc.; also includes direction provided to operators under the dispatcher's jurisidiction.

Determine equipment status: Actions taken by the dispatcher to determine the status of both internal and external equipment. These actions might include status checks performed through the control system (CTC), telephone equipment reports, or work/maintenance crew reports.

Establish routing: Preplanning by the dispatcher for traffic routing via the most expeditious line to reach destinations. Also includes alternate routing the dispatcher might select in order to move through traffic around potential or existing traffic problems.

Establish scheduling: Actions taken to establish track occupancy time schedules for mainline traffic, maintenance crews etc.

Receive traffic advisories: Includes receipt of information derived from external sources dealing with the traffic situation, i.e. track conditions, delays, early reports, weather conditions, traffic volume, etc.

Monitor/initiate communications: Includes all incoming and outgoing audio communications between the dispatcher and other railroad personnel.

Issue traffic advisories: Information as in Receive traffic advisories above transmitted to an external agent.

Initiate system control actions: Control of train movements/operation through manipulation of system.

Issue/annul train orders: Action which a dispatcher takes both through use of communications channels and documentation when issuing or cancelling a train order.

Issue hi-rail operation permits: Permission which the dispatcher gives a maintenance crew, wrecking crew, or special vehicle to occupy a particular segment of track.

Receive/relay weather advisories: Dispatcher receives and relays weather conditions; the frequency of advisories of course varies according to the nature of weather conditions as they influence traffic flow.

Experience communications problems: Includes any malfunction, degredation, or disruption in communications either locally or remotely initiated. Also included are the frequent busy signals and unanswered calls which the dispatcher encounters when trying to contact other parties.

Respond to internal equipment failure: Actions the dispatcher takes to restore the CTC, hot-box recorder, or internal comms. equipment to normal operation. His response might be in terms of immediate corrective action performed on the malfunctioning equipment or call for maintenance required for correction.

Respond to external equipment failure: Similar to above except that the activity is limited to actions taken by the dispatcher when external/remote equipment malfunctions, i.e. signalling and switching equipment, power failures, etc.

Respond to unplanned events: Response the dispatcher makes whenever events arise which are not according to his normal daily planned routine. The train dispatcher is usually the coordinator for all preventive or corrective actions taken whenever unplanned incidents arise. Examples of unplanned events include results of weather conditions, deterioration of roadbed, operation without clearance, etc.

Respond to emergency conditions: Similar to above except that the associated level of urgency is much higher. Typical emergency conditions are: train derailment, train collisions, severe weather conditions, structural collapses, etc.

Transmit train clearances: For example, transmit clearance for a train to enter mainline from siding or from yard using radio or telephone message relay.

Receive clearance/permit request: Request received from trains to enter or cross mainlines, side tracks, or yard areas.

Receive/transmit train position request: Request from operators, signalmen, towermen, etc., regarding exact position of a particular train.

Perform equipment adjustments: Immediate corrective action taken by the dispatcher to return equipment to normal level of service.

Receive/transmit information request: Audio communications between the dispatcher and other railroad personnel concerning the interchange of information to facilitate operational procedures. Information received or transmitted relative to train consists is also included in this section.

Conduct business outside of work area: Includes any direct coordination or instructional activity conducted outside of the dispatcher's immediate work area.

Coordinate work crew requirements: Actions which a dispatcher takes in determining/directing work crew activities. This would include the initial identification of category of support required and coordination of these requirements, along with follow-up communications while maintenance or wrecking crew procedures are being performed.

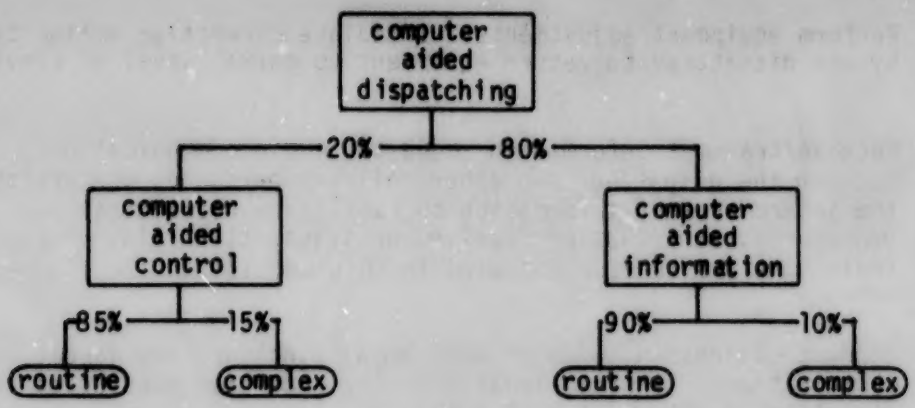
Non-operational absence: Any period in which the dispatcher is away from his work area for non-operational purposes, e.g., restroom, sickness, personal business, lunch breaks, etc.

7.6.4 Automation Potential of Dispatcher Workload

Analysis of the dispatcher's work effort show that this effort can be categorised into two main headings:

1. system control
2. information gathering (clerical)

Of the two our collected data lead us to believe that approximately 80% of the dispatcher's time is spent performing the clerical effort and 20% is spent on actual control. Of the 80% clerical effort it was determined that 90% of it is routine (maintenance of train sheets, train graphs etc.) and only 10% requires any real dispatcher input. Of the 20% expended on control, about 85% of it is routine (clearing signals ahead of a train or clearing a train out of a siding) and 15% is of a complex decision making nature requiring additional thought processes and actions by the dispatcher.



It can be seen from this diagram that the total for routine tasks is (0.85 x 0.20) + (0.9 x 0.8) x 100% which gives 89%. Thus what this adds up to is an approximate 90% automation potential. It is this 90% automation potential that makes a computer a very valuable tool for aiding in the performance of the dispatching task. This fact has led to the development of Automated Dispatching techniques utilizing computers to perform routine tasks.

The functions of an automated dispatch system can be categorized as primarily those of automatic or computer aided control and dispatcher information processing.

System functions - computer aided control
- dispatcher information system

Computer aided control system

This system deals with control system supervision, train tracking, the alignment of routes, clearing of routes, and resolution of conflicts.

System functions:
- control system supervision
- train tracking
- route lining
- route clearing
- conflict control
- blocking
- manual override

Computer aided control permits the reduction of the Dispatchers workload, the reduction of train delays, and the enhancement of the information data base.

System effects - reduce dispatcher workload
- reduce train delays
- enhance information database

Dispatcher information system

System functions - local entry
- remote entry
- dispatcher aids
- local hardcopy
- remote hardcopy
- control system interface
- MIS interface

System effects - reduce dispatcher workload
- improve train control
- reduce clerical workload
- enhance crew handling data-base
- enhance loco handling data-base
- enhance resource MGT data-base

8. MAINLINE USER REQUIREMENTS

The results of the Canadian Pacific Rail site specific study described in Part 7 of this report together with general railway experience led to the following definition of user requirements for mainline application of the LIC system.

(a) Full control of trains in LIC territory must be provided from a central dispatching office.

(b) The system must have the capacity to schedule and control efficiently up to 35 movements per day. In addition, up to 20 trains must be handled at any one time.

(c) The dispatcher must be provided with a precise display of the status of all trains, signalling, and remote equipment. This display should use colour graphics techniques to allow anticipation of the future clearance needs of trains.

(d) The engineman must be provided with a locomotive cab signal and information system to present continuously updated data on track conditions ahead of the train. This feature will make possible operation according to "electronic vision" to allow, for example, safe deceleration to the tail end of a train ahead.

(e) Power switch control must be provided to minimize delay at meets, passes, and diverging junctions. Conventional techniques should be used to ensure that movable points do not traverse during passage of a train. Furthermore, routing over switches must preclude the set-up of conflicting or unsafe routes.

(f) Fixed automatic block operation to APB standards should be provided to control cab signalling between siding ends on single track.

(g) Automatic train protection of the braking-after-warning type should be provided to ensure engineman vigilance and compliance with cab signalling commands. Braking distance will be computed from a fixed track profile supplied by the Railway.

(h) The engineman should be provided with a display of fixed roadway speed limits, and the system should monitor actual train speed versus limit to check for overspeed. During ATP command braking the speed limit should be rolled off according to the profile mentioned in (g).

(i) The dispatcher's system control task should be aided by computer to provide automatic route clearance, meet and pass scheduling, and conflict prediction.

(j) The system must support a comprehensive dispatcher information system to remove the burden of routine clerical duties and to meet management and legal requirements.

(k) Remote emergency brake application should be provided for the dispatcher to stop a specific train when it is running under conditions which could be hazardous to safety.

(l) The system should allow initially for the operation of LIC and non-LIC equipped trains.

The functions outlined above form the basis of an advanced train control system that could provide a significant level of expansion to traffic on lines presently under train order or MBS control. The design of such a system must also take into account the following additional requirements:

- the system should be suitable for use by all North American railways.

- the system must be fail-safe such that a failure will not cause operation to be less safe than it was before failure.

- modular design should be employed, thereby making the system suitable for all railway configurations.

Continuous data exchange must be ensured between the control centre, train system, and other remote devices.

- the system has to be constructed for speeds up to 200 km/h.

- implementation should be possible in logical steps as warranted by traffic capacity and capital expenditure requirements.

- the system design must assure high reliability, availability, and maintainability.

- operation must be backed up by a fixed set of regulations and operating rules to ensure safety in the event of system failure.

The existing LIC system embodies many of the features described above, and the others are seen as logical extensions. As far as LIC software is concerned, however, it would be necessary to develop a considerable number of new modules in order to provide the extension features.

9. CONCEPTUAL DESIGN FOR MAINLINE RAILROADS

Part 8 of this document outlined the perceived user requirements for mainline railroad application of the LIC System. On the basis of these requirements a detailed conceptual design for mainline applications was drawn up and is presented in full in Reference 9. This part summarizes the main points of the conceptual design.

9.1 LIC Traffic Control

LIC uses fixed block control in conjunction with locomotive cab signals to authorize train movements. LIC cab signal indications supersede the superiority of trains for both opposing and following movements on the same track.

The limits of each block are designated as Control Points (CPs) and are marked by CP signs and the presence of DIGITRAC transponders. Three transponders are placed at each main track switch and two at intermediate locations where necessary. Train location is by on-train interrogation of transponders, supplemented by locomotive odometer reading. The transponder crossings reported at a given Control Point uniquely identify the location and direction of the train and the route taken at a switch.

Authority for train movement is given by cab signalling instructions transmitted directly to the train by data radio. A locomotive cab display gives the engineman plain-language commands either as computer by the control centre system or as entered by the dispatcher. The cab display shows the authorities in force for the current block and the next two blocks ahead. In addition, the display indicates train location as subdivision mileage, the current speed limit, and the train speed.

The LIC System automatically protects against authorization of unsafe or conflicting train movements. The system maintains duplicate independent track occupancy/authority data bases using information derived from transponder crossing reports. LIC employs Absolute/Permissive Block (APB) control between sidings to expedite following movements and ensure safety.

Power switch control is provided where necessary by means of the LIC Radio Switch Control Unit (RSCU) which communicates with the central control system by data radio. The RSCU controls the alignment of a power switch on command from central, returns a positive indication of completion of switch movement, and confirms the position of the switch on request. All track within the fouling points of the switch is track-circuited. Occupancy of track in the immediate vicinity of the switch is reported to the control centre in order to protect against switch operation

during passage of a train. In addition, if the railway employs last vehicle detectors in lieu of cabooses and their associated LIC equipment, the RSCU will detect and report last vehicle passage over the switch to indicate that the preceding block is clear.

A suitable graphic display gives the LIC train dispatcher a continuously updated picture of the status of all blocks, switches, control points, and trains. The system communicates with adjacent LIC territory to permit automatic transfer of trains between territories. The system also allows for manual handover of control between LIC and adjacent CTC territory without delay.

9.2 Automatic Train Protection

Under Automatic Train Protection (ATP), the LIC System supervises the safe movement of trains at the prescribed speed limits and initiates train braking in the event of a potentially unsafe condition. The ATP function is advisory in nature, placing speed regulation in the hands of the engineman. The system causes an audible alarm to be sounded in the engine cab at a computed distance from a restriction. Engineman vigilance is assured by an automatic penalty brake application after warning if a restrictive command is ignored or upon failure to correct an overspeed condition.

Train speed and speed limit data are interleaved with normal LIC signalling communications. The control centre transmits the current speed limit according to train location. The limit is shown on the cab display and must be respected while any part of the train is in the area subject to that limit. The train dispatcher is provided with the capability to initiate an emergency brake application on a specific train if the engineman fails to respond after an audible emergency warning.

9.3 Automated Train Dispatching

Automated dispatching comprises two functional areas: computer aided control and the dispatcher information system.

9.3.1 Computer Aided Control

The LIC central control system automatically transmits route authorities and lines switches in advance of a train's position when track occupancy conditions permit. Computer aided meet control analyzes the requirements and characteristics (relative priority, power, length, tonnage) of opposing trains as well as trackage (siding lengths, grades) in order to set optimum meets between opposing trains. Where power switches exist they will be lined automatically to minimize delay. A similar capability is exercised with respect to pass control of following movements.

The system uses train performance algorithms and current track conditions to perform automatic prediction of conflicts between trains. LIC controls and monitors all track occupancy permits and advises the dispatcher of pending time expiration. While permits are in force, the system prevents clearance of routes into occupied blocks.

The LIC dispatching system may be operated in either manual or automatic mode. In the latter case the dispatcher assumes full responsibility for all train movements and authorities but may base his or her actions on information provided by the system.

9.3.2 Dispatcher Information System

The LIC central computer maintains an efficient and detailed information system which relieves the dispatcher of many routine clerical tasks. In a sense, the heart of this system is the automated train sheet which contains all of the data normally entered on a conventional train sheet together with some additional information.

A remote data entry terminal permits the chief dispatcher to order trains and enter such information as train ID, engine and van numbers, cars and tonnage, and crew data. Local entry by the train dispatcher of movement control directives, manual OS reports, and other information allows the system to schedule movements efficiently. Train tracking data are automatically entered by the computer. Any part of the train sheet may be displayed on the terminal screen and updated from the keyboard. In addition, the system prints a copy of each train sheet automatically at the end of the day or at any other time on demand.

The system supports a complete set of dispatcher aid displays including: train performance reports; train order review; block and clearance status; track lineup; and others. In each case the system will also provide a printed copy on request. Furthermore, the system prints for historical record the results of any function performed that affects the control or performance of a train. Typical records would include track occupancy permits, lineups, and changes in meets.

Another function of the information system is to enable efficient management of train crews. The system schedules duty and rest times according to the railway's crew operating plan and maintains a file of crew performance by accumulated miles and hours. The system is thus able to advise the dispatcher and crew clerks if a train crew's 11-hour on duty time limit is about to expire and to provide optimum replacement crew information.

Finally, the LIC dispatcher information will automatically alert the dispatcher to any predesignated event, e.g., pending expiration of a track occupancy permit, and to any system status or operational alarm condition.

10. CONCLUSIONS

10.1 General Conclusions

This report covers diverse aspects of the appliction of LIC to mainline railroads. It includes a description of the LIC System, and a definition of an advanced traffic control system for mainline railroads. With these as background, certain functional extensions to the LIC System are discussed. The feasibility of these extensions, which will be necessary for the future growth of the system, is established. The development of the central office Data Collection Processor (DCP) hardware and software as implemented in the B. C. Railway LIC System is described. The DCP is then evaluated from the viewpoint of its ability to handle the B. C. Railway job and its capacity for expansion to handle mainline railway applications.

A specific mainline railway application, the Canadian Pacific Windermere and Fording River subdivisions, is analyzed in detail, and a set of User Requirements for this territory is defined. With the existing LIC System as a foundation, a conceptual design for a generalized "LIC for Mainline Railroads" is proposed. A great deal has been learned from the foregoing work about both the features and capabilities of LIC and the requirements of some potential users.

When first fully defined as a system, LIC was based on the principle of dynamic block separation between trains, and only the present and approaching speed limits and their location were displayed to the engineman. The concept was to run trains at optimal speed by supplying precise digital speed limits as opposed to the coarsely quantized limits encoded into coloured light or semaphore signal indications. Absence of a discrete speed limit or a failure alarm would require trains to clear main track at restricted speed as soon as possible.

In planning the operational requirements for B. C. Railway in 1979 it was recognized that a great deal of critical software conceptualization, design, and implementation would be required to produce a dynamic block system that was reliable, effective, and safe. The risk perceived by the customer and by the industry in general was high. Therefore, it was decided to revert to the present fixed-block organized system whereby trains must receive specific authorization to pass each control point. Absence of authorities requires that the train stop. When system concepts were being discussed it was contemplated that train orders might be sent to the train, but it was concluded that this procedure would be impractical. The large amount of text to be transmitted would require excessive communications bandwidth, and the great variability in content between different orders would make computer checking difficult. Hence LIC became in essence a computerized manual block system.

The LIC installation at B. C. Railway must now be considered a success. At the time of this writing the system is a few weeks away from full customer acceptance. Sufficient testing and operation have been done to provide a high level of confidence that the small amount of work now remaining will be completed successfully. In viewing the system virtually complete we are able to assess its strengths and weaknesses realistically.

10.2 System Capacity

The capacity of the LIC system has been of great interest and some concern. A rough analysis had shown that with a complex polling algorithm the system might be capable of handling up to 22 trains simultaneously; however, in the actual event a simpler and more practical algorithm was used. This factor together with others which are discussed below, results in a capacity of up to 10 trains at one time. Although this is a significantly large number which will serve B. C. Railway's requirements for a considerable time, it is a potential limitation. The following paragraphs discuss factors affecting system capacity.

10.2.1 Radio Coverage

The number of times that messages must be repeated has a large influence on overall system capacity. The present requirement is for a 70% level of coverage, i.e., at least 70% of all messages must be received correctly on the first attempt. This level, though adequate at present, could be improved to reduce overhead time. Details of the communications coverage are also important: coverage should be as uniform as possible over the entire length of the controlled territory. If coverage varies between 95% and 45%, it may well average 70% overall, but severe deterioration in performance will occur in the 45% regions. This problem can be minimized by careful engineering of the radio installation.

10.2.2 Communications Data Rate

Under the present system, DCP-ELU communication operates at 300 bits per second (BPS); this rate is slow by present standards. Data rates up to 2400 bits per second can be achieved successfully, and the existing train and DCP hardware has been well proven in operation at 1200 bps. Thus an immediate improvement by a factor of 4 appears to be available at low risk.

The implication of higher speed, however, is that the communications channelling must be redesigned. At present, five 300 bps data channels are multiplexed into a single voice-grade trunk channel. If 1200 or 2400 bits per second were used, each data channel would require a full voice-grade channel, and this arrangement would be excessively costly. The proper scheme for

higher data rates is to make the remote communications sites individually addressable and to use a single channel multi-drop design. The implications for the DCP software are that the channel select software must be changed and a remote site address introduced into the message packet. Furthermore, the Remote Site Unit (RSU) must be redesigned, and although this is a large task it has a low associated risk.

10.2.3 DCP Capacity

The DCP is an eight-bit microcomputer which, although powerful, has a limit to its processing capability. Its primary tasks are communications processing and safety checking. In the final implementation a large proportion of DCP processing time and memory has been devoted to safety checking and related tasks, and full utilization of its capacity is being approached. If the DCP becomes a bottleneck for the system, however, there are avenues available to alleviate the problem. The most obvious approach is to identify the module or modules which are causing the delays and then to rewrite them to be more efficient. With the significant amount of software "adjusting" required to fix problems and/or implement features and details not recognized earlier, it is known that several modules have been stretched to the limit of their capacity as designed and that a redesign/rewrite would be beneficial although it is not necessary at present.

10.2.4 Dispatcher Interface

The dispatcher interface uses a combination of alphanumeric and special function key entry on a video terminal. Initially, each control point instruction was entered in full manually. Radio communications problems were causing a high percentage of failed transactions at this time as well, and the dispatcher workload was intolerable. The situation was much improved after implementation of a single entry "REPEAT" key to advance the issuance of control point instructions to a train once it has been identified by the system. Further improvements resulted from a general increase in communications effectiveness and from the dispatchers' tendency to avoid issuing instructions to trains in known areas of poor communications. It appears now that dispatcher capacity is about the same as that of the communications system, i.e., 10 trains at one time.

The capability of the LIC System to handle a specific application ultimately will be determined by the details of that requirement: the number of radio sites, length of track, number of trains, and additional capabilities, such as power switches, as discussed in Part 4. Although an attempt has been made to generalize and modularize the System, it is recognized that each application will be unique, and at that at least some degree of customization will be required for each new implementation.

10.3 Alternative Proposals

The type of system discussed in Part 8, with all features included, would require a significant amount of engineering to implement. This fact, coupled with the risk of choosing a new concept for traffic management makes potential customers reluctant to make a full-scale commitment to LIC. Therefore, the various elements of the system such as: the Host computer, track diagrams, and keyboard; the locomotive to DCP data link; and train location by transponders and odometer logic are being looked at with a view to their use, as component elements, to assist railroads in various areas of need. In the following paragraphs we consider some typical areas of application.

Manual Block operations are being increasingly implemented by both Canadian National and Canadian Pacific Rail in Canada. This method of traffic control places a heavy burden of responsibility for safety on the train dispatcher. The Host computer, track diagram, and keyboard portion of LIC, set up as a stand-alone system, can provide valuable computer assistance to the dispatcher and thereby improve both efficiency and safety.

Several systems for event recording and health monitoring on board locomotives are currently available from various suppliers (Vapor, Hasler, Harris, Pulse). All are characterized by either on-board tape recorders or solid state memory modules which store trip data until it can be retrieved from the locomotive by manual means. Real time data collection via radio link would greatly enhance the performance of these systems in a number of ways by eliminating unreliable mechanical elements (tape recorders) and error-prone manual handling of the data, and by enabling real time response to critical areas of information.

Finally, several attempts have been made in the past few years to introduce computer decision making into the computer-aided Centralized Traffic Control (CTC) systems which use conventional track circuits for train location. These attempts have not been particularly successful, primarily because the precision of the train location and speed data has not been sufficiently high. The high precision ($\pm$0.1 mile, $\pm$0.1 mph) of these data in LIC make it an ideal candidate to be overlaid on conventional CTC. The LIC System, relieved of its primary responsibility for train safety by the existence of conventional signalling equipment, is a much less contentious risk to the railroad. We believe that a LIC installation will show an attractive payback through improved train operating times and increased fuel efficiency.

Three alternatives to the direct proposal of LIC as a computerized central traffic management system have been described, and these will be further investigated. There is no less interest in providing LIC in its primary role of traffic

management, but these alternatives broaden the range of possible applications. The advantage of using a subset of the present LIC System is that the probability of success is very high and the path of growth to increased capabilities is clearly observable in the B. C. Railway LIC installation.

LIC will soon be fully operational at B. C. Railway. This statement answers the question: "where is this system used now?" and greatly adds to its credibility. The viability of the LIC concept is readily confirmed by that installation, and any scepticism on the part of prospective users is removed. Thus, notwithstanding the desireability of the extensions and additional features discussed in Parts 4 and 8 of this report, additional purchasers of the system should be found before further extensions of the system are developed.. A high priority must now be placed on finding applications for the existing LIC system and subsets of the system.

10.4 Recommendations

As a result of this study of the possible application of LIC to mainline railroad use, the following recommendations are made:-

1. No further development work should be done on the LIC System.

2. Purchasers of the existing system or subsets of it should be vigorously pursued.

3. Extensions of and/or modifications to the system should only be entertained in the context of a fully funded effort on behalf of a customer with both need and justification.

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APPENDIX 'A'

Contract Statement of Work

APPENDIX 'A'

CONTRACT STATEMENT OF WORK

1. STATEMENT OF WORK

1.1 Overall Objective

The application of Location, Identification and Control (LIC) signalling technology to provide for safe and economical control of train movements on main line National Railways.

1.2 Specific Objective

Initial study and software design to evaluate the feasibility of utilizing the LIC System on the Fording River and Windermere Subdivisions of C. P. Rail between Fording and Golden, British Columbia.

1.3 Detailed Statement

The work to be carried out shall be consistent with this proposal, and shall consist of the following tasks:

1.3.1 Prepare and submit to TDC a detailed project work plan and schedule in SPEC, or equivalent form, plus a cash flow diagram of the projected expenditures, within three weeks of contract award. These documents shall be reviewed by TDC and modified by the contractor as necessary until a mutually agreeable plan for proceeding with the work is established.

1.3.2 Carry out technical studies, design analysis, software preparation and test work relating to development of a Data Collection Processor (DCP) unit for the LIC system which will be suitable for main line railway applications. The following work items shall be specifically addressed:

1.3.2.1 Consult with C. P. Rail, VIA Rail, other selected North American railway companies, and representatives of the Railway Transport Committee of the Canadian Transport Commission to define the scope of application for the LIC System to the control and monitoring of train movements.

1.3.2.2 Prepare a LIC System definition of the control of train movements on main line railways. This will include modularization of the System both geographically and in terms of summarizing alternative types; of wayside communications trunks which can be used to transmit data between the dispatch centre and the wayside equipment. Identify any restrictions to the use of the LIC System due to the type of railroad or from operations regulations. Propose solutions to known potential operating problems such as exchanges of locomotive power, elimination of cabooses and dispatching of non-equipped trains and equipment.

1.3.2.3 Define additions and changes to the DCP and to the Engine Logic Unit (ELU) and other train on-board hardware that may be necessary to provide extension in operational capability of LIC. Candidate extensions include:

a) remote activation of locomotive/train brakes

b) provision in the ELU of updated speed limit based on track location

c) monitoring of current speed limit against current speed, and the actuation of penalty service brake application for overspeed

d) prediction of braking distance based on speed and train characteristics

e) use of predicted braking distance to determine the safety of operation of a train approaching a red signal or stopping point

f) remote control of switch points

1.3.2.4 Define and specify techniques of safe programming such as logical redundancy which are practical for implementation in the DCP and which will form part of the programming standard for LIC software in the DCP.

1.3.2.5 Specify program changes required in the DCP software to implement the capabilities defined in the preceding tasks.

1.3.2.6 Evaluate the DCP hardware and train on-board equipment to ensure that sufficient capability exists to implement the programming specified in the preceeding tasks.

1.3.2.7 Re-organize existing DCP software structure, and ensure that the operating system and real-time scheduling can accommodate additions to the applications software.

1.3.2.8 Design, program, install, debug and test a selected set of the programs as specified in the preceding tasks to evaluate the technical feasibility of the proposed design concepts.

1.3.3 Evaluate the feasibility of designs as implemented in paragraph 1.3.2.7 and carry out a site-specific study into the application of the LIC System to control unit train movements and other traffic on the Fording River and Windermere subdivisions of C. P. Rail between Fording and Golden, British Columbia. The following work items shall be specifically addressed:

1.3.3.1 Investigate and acquire a thorough understanding of the C. P. Rail operating procedures, regulations and practices on the Fording River and Windermere Subdivisions.

1.3.3.2 Prepare operating scenarios for the use of LIC both over the train order territory and any CTC block signalling territory of the Fording River and Windermere Subdivisions of C. P. Rail.

1.3.3.3 Evaluate the incorporation into the LIC Engine Logic Unit (ELU) and Data Collection Processor (DCP) of train dynamics information such as power and/or braking recommendations as a function of the train position, speed, direction, length, weight, and other parameters, as well as the important track physical parameters such as grade and curvature.

1.3.3.4 Prepare in conjunction with C. P. Rail, a LIC System specification which covers the scenario and those additional train dynamic functions which are incorporated.

1.3.3.5 Carry out the system design, hardware configuration and cost estimates for the LIC installation based upon the specification agreed to with C. P. Rail and TDC.

1.3.3.6 Evaluate in conjunction with C. P. Rail, the operational and economic justification for LIC signalling on the Fording River and Windermere Subdivisions. Also make estimates as to the justification of LIC on other sections of main line railway track based upon the experience gained in the detailed analysis of these two subdivisions.

1.3.4 Prepare and deliver to TDC reports on the work carried out and the results achieved in accordance with the Reporting Requirements (Section 7 of Appendix A of the Request for Proposal).

1.4 Comments

The above detailed statement of work, reflects the requirements of the "Request for Proposal" and presents an expansion of activities as originally proposed by our unsolicited proposal "Applications of LIC to Mainline National Railroads" dated July 1981, and submitted to Supply and Services Canada (DSS), Science Procurement Centre. The following expansions in work and concept are identified:

1.4.1 Project work plan and schedule, and cash flow diagram, as specified by paragraph 4.1 of the Request for Proposal.

1.4.2 Detailed and specific consultations as required by paragraph 4.2.1 of Appendix A of the Request for Proposal.

1.4.3 Examination of the problems associated with the elimination of cabooses, as identified by paragraph 4.2.2 of Appendix A of the Request for Proposal.

1.4.4 Extension of systems to include the facility to provide "Remote Control Of Switch Points" as identified by paragraph 4.2.3 (f) of Appendix A of the Request for Proposal.

1.4.5 Inclusion of train length and weight parameters in the evaluation covered by paragraph 4.3.3 of Appendix A of the Request for Proposal.

1.4.6 Preparation and delivery to TDC of a final report as specified by paragraph 4.4 of Appendix A of the Request for Proposal.

Appendix 'B'

Mainline LIC Project Working Paper - MWP7

LIC Safety

APPENDIX 'B'

MAINLINE LIC PROJECT WORKING PAPER - MWP7

LIC SAFETY

1. INTRODUCTION

Systems for railways can be categorized by two distinct levels of control, only one of these directly affecting the safety of trains. Non-vital levels, concerned with train description, route setting and information etc. have already been successfully computerized. However, on vital tests of control where block signalling and interlocking are concerned, the problems of computerization were not so easily resolved. In this case the major problem was that of producing a system that would be fail-safe in the sense that no equipment failure should give rise to an unsafe condition.

The characteristic which provides this fail-safe operation is often referred to as the 'safety' of railway signalling applications. If we consider the nature of this characteristic it can be seen that safety is a probability parameter and that 100% safety is in practice unattainable. Therefore, since failures cannot be totally eradicated, appropriate measures must be taken to detect faults and ensure that connected circuits are placed in a safe or de-energized state.

When considering the application of computers to vital systems, such safety assurance cannot be predictably guaranteed. The reason for this lies in the complex nature of the circuits within the computer itself and their unpredictable failure modes. Therefore, unlike the conventional vital relay systems, computers exhibit a multiplicity of unknown and complex failure modes.

The LIC system is a fixed block control system that relies entirely on computers for the performance of safety tasks. In order that the safety shortcomings of this computer based system be overcome, techniques for fault detection and isolation have been developed to provide the necessary level of fail-safety.

2. FAIL-SAFE REQUIREMENTS

The LIC system has been developed in line with the fail-safe concept by choosing a system configuration and mode of operation which assures the safe outcome of any failure which may occur. The criteria used to define fail-safe operation are generally given as:

- A failure must not cause the system to be less safe than it was before failure.

- If the failure is not revealed immediately after it has occurred, it must be considered in combination with all possible subsequent failures.

In the LIC system where the central computer governs the safe issue of fixed block authorities to the train, the requirement may be specifically stated as:

- A failure must not result in the system believing that a block of track is free for occupancy, when it is already occupied or could be occupied by a train complying with previously issued authorities.

- A failure must not result in an engineman believing that he has authority to occupy a block of track, when no such authority has been given.

These requisites apply to primordial safety as it affects the control of train movements. This should not be confused with operational safety which can be provided by non-vital tasks of the system.

The design used to satisfy such requirements must be analyzed to determine the effects that failures may have on safety. These effects must be well documented and reviewed by persons other than the original designers. This will ensure that all possible failures have been considered and that the safety design features are adequate.

3. LIC SAFETY

3.1 Assigning the Safety Tasks

The LIC system and most similar railway systems can be broken down into three main subsystems: the central office system, the data transmission system, and the remote field equipment.

The decision on whether the data transmission system must be of a fail-safe nature is dependent upon where the safety tasks are located. The safety task assignments for the LIC system are given in Fig. 1. In this system, the central computers control via the data transmission system the movement authorities displayed to the engineman. Vital information regarding the

location of trains is sent by the data transmission system to the central computer. This computer then takes over the interlocking function and related safety tasks to ensure fail-safe control of block sections. It can be seen in this case that all the safety tasks are assigned to the central office and that the data transmission system must be fail-safe.

The requirement for safety in LIC can only be met by ensuring the validity of vital data reaching the central office. This system must ensure that only safe operator inputs are passed for output by the interlocking system. Lastly, the output authority must be safely transferred to the train without corruption.

The assurance of fail-safe operation is made possible by adopting for each step the optimal technique for ensuring safety; the additive nature of these stepwise processes will thus ensure the safety of the entire process.

With the assignment of safety tasks to a computer, increased flexibility is available. This results in a reduction of effort necessary when carrying out alterations, be they modification of control programs or modification to the track layout in the form of topographical changes.

3.2 Vital Data-Collection

The collection of location information from the train-borne field system provides the vital data necessary to construct diverse data bases within the central computer. It is the integrity of these data bases which ensures correct conflict and safety checking. Special measures must be taken to ensure the integrity of this data, firstly from the initial detection viewpoint and secondly in being transferred to the central computer.

Interrogation of passive wayside transponders by the train-borne system provides a unique 4 digit code which can be translated by central to geographical location. These transponders are laid in pairs at the limit of all fixed block sections, known as control points (CP).

The validity of the 4 digit code produced by interrogation of transponders is ensured by the following methods:

- The serial data transfer from the transponders is synchronized with the on-board clock to ensure that framing errors do not occur.

- While synchronization is maintained, a maximum of seven frames of data are captured, if less than three are captured, the transfer is aborted and retried.

- The resulting data are truncated to three, five or seven frames for the purpose of majority voting. Voting is carried out at bit level on the basis of 2 from 3, 3 from 5, and 4 from 7 voting for 3, 5, and 7 frames of data respectively.

- The resulting frame of data contains a cyclic redundancy code, BCH (31, 26) with a Hamming distance of three. This provides a high immunity to bit and burst errors and ensures the detection of all one and two bit errors.

- The resulting frame is also checked to ensure that the synchronization character is correct and that the data modulus for each of the four BCD digits is within the prescribed range.

The combined effectiveness of these methods provides a highly secure method of obtaining the correct 4 digit code from the transponder. In fact the security provided is such that the probability of an incorrect code being accepted is extremely low. Duplication of transponders at control points ensures that if a single transponder is missed, safety can still be maintained. In this case the central computer will be alerted by the resulting break in code sequence continuity.

To provide safety in respect of equipment failures, the train-borne interrogator is continually checked to ensure that the electromagnetic field is present, loss of field causes a system failure to be flagged. The engine logic unit (ELU) is protected against faults by a watchdog timer, which is the lowest priority task in the multi-tasking operating system. If the task does not run due to a fault, the timer expires and the unit fails itself and places all outputs in a safe state.

When the engine logic unit's transponder buffer is holding one or more transponder crossing records, it automatically incorporates the oldest record into its response to a regular train poll. The record is then transferred back to central; however, the ELU expects to receive an acknowledgement of this transfer. The acknowledgement includes an echo of the transponder number, which when confirmed allows the ELU to delete the record from the transponder buffer. The transfer of the vital transponder code is thus assured by this initiate-confirm-execute routine.

In addition to the security provided by this method, the message protocol used on all train to central transfers is highly structured and makes use of the following error detection methods:

- Messages are block organized with four byte blocks and an overall block parity check bit.

- Cyclic redundancy codes, BCH (31, 26) with a Hamming distance of three detect all one and two bit errors. This type of coding provides high immunity to bit and burst errors.

- Communications timers operate at each end of the link, to ensure that a reply is received to a message within a pre-determined time. Time-out results in the present message sequence being abandoned.

- Syntax and context checking of messages ensures that the format is correct and that the content is relevant to the present transaction in progress.

The stringent handshake procedures together with error detection, provides the required assistance of fail-safe transfer of vital transponder crossing data. This data can thus be used with confidence for safe update of the central computers block occupancy data base.

3.3 Central Computer Interlocking

The use of computers in the interlocking task is governed by the requirement that every fault should lead to a safe operational condition. The major limitation in respect of this requirement, is the unpredictable nature of the failure modes exhibited by complex LSI circuits used in the computer architecture. In designing a system to be fail-safe under these conditions, the following must be specifically considered.

- hardware faults
- component failures
- E.M. interference
- systematic errors
- software errors

It has been demonstrated that in practice the last two of these prove to be the predominant factors in system safety. The reason for this lies in the succeptability of the complex circuits and operational software to systematic errors, i.e., errors that occur only under certain specific conditions due to an inherent design error.

In redundant systems where the results from two similar processors are compared before an output is activated, failure of the systematic type may lead to a good comparison and possibly a dangerous situation. As the conditions for such a failure are so specific, it is unlikely that it would be detected during system test. It is more likely to avail itself when the system has been commissioned and is in operation.

In the LIC central computer, safety is achieved by a dual processor solution according to which the interlocking process is carried out by independent programs. These run in two different processors, namely the Host and DCP. Diversity is afforded by having independent data bases in each machine, together with different versions of the general safety checking programs. The method is optimized by having computers from different manufacturers and programs designed by independent teams in different software languages. This configuration ensures safety in respect of systematic errors in the computers and also in the high level software compilers used.

Input data for the interlocking process is independently derived from transponder crossing reports and is stored in separate data bases in the Host and DCP. Diversity is afforded by the fact that each resides in a different processor and is programmed in a different language: Pascal for the DCP and Fortran for the Host. Thus errors will affect each in a different manner and the data base agreement required for issuing output authorities will not be met.

The DCP has access to transponder crossing data directly from the train polling task and uses this data to make entries for each block of track. The date base is modelled on the track layout, with provision for an entry for each block containing the train ID, the block number and the authority issued for the block. The data base is updated according to the following criteria when a control point (CP) is crossed:

- when the front of train unit crosses one or both of the transponders at a CP, the blocks on both sides are entered as occupied.

- when the front of train unit crosses an approach transponder at a switch CP, the approach block, main track block and diverging track block are all entered as occupied. When the second transponder is crossed, the block occupancy in the excluded route is cancelled.

- when the rear of train unit only crosses one transponder at a CP, the block to the rear of the train remains entered as occupied.

- when the rear of train unit has crossed both transponders at a CP, the block to the rear of the train is entered as clear.

Thus it can be seen that if only one transponder is detected at a control point, the system assumes both blocks are occupied which represents a right side failure.

The Host's data base is organized in a diverse manner to the DCPs, with separate tables for blocks occupied, block authorities and train authorities. The data base is updated in a similar fashion to the DCPs, using transponder crossing data requested from the DCP every second and a half. The fact that the two data bases have been implemented in different ways means that it is almost inconceivable that the two could be corrupted in a fashion which would lead to an erroneous output. Thus by ensuring that operator inputs are checked by both data bases independently, safety can be assured.

When an authority is entered into the system, it consists of the train ID, the control point number, the direction, and route; these define the blocks of track to be output to the train's cab display. The sequence of events when then take place are shown in Fig. 2 where it can be seen that the Host and DCP both perform a series of checks on the authority. These checks are carried out according to the safety checking specification and consist of two main categories, prerequisite checking and conflict checking.

The prerequisite checks ensure that the authority is acceptable in terms of continuity, compliance with operating rules and type, etc. The conflict checks are more stringent and specifically check for the following:

- Block availability
- Route
- Opposing conflicts
- Following conflicts
- Train ahead restrictions
- Computer protection requirements

If the authority is found to be safe, then the relevant data bases are updated to show the authorities issued and thus the blocks taken. For the authority to be passed for output to the train, it must have passed the acceptance tests of first the Host and then the DCP.

The diversity in this interlocking process ensures that the probability of the central computer outputting an unsafe authority is low enough to satisfy safety requirements. However, the authority must still be transferred in a safe manner to the cab display, otherwise all previous safeguards will have been in vain.

3.4 Authority Transfer

The authority transfer sequence makes use of logical redundancy techniques, whereby the cab display line is derived via two diverse program paths. The general sequence during such a transaction is shown towards the bottom of Fig. 2, then in more detail in Fig. 3.

The authority transfer begins after the completion of the safety checking process between the Host and DCP. At this point, the DCP has an authority consisting of the control point number, direction and route. Before the authority is sent to the train, coded versions of the control point number, direction and route data are generated using a (15, 11) BCH code generation algorithm. The coded versions are included with the originals in the message sent to the engine logic unit (ELU). This transfer utilizes the same protocol and error detection techniques described in Section 3.2. Upon receipt at the ELU, both versions are echoed back to the DCP in the confirm message and are stored in a separate area of memory to the data originally transmitted.

The coded versions of the fields in the echoed message are now compared with the coded versions from the original message. Only if the two versions are identical is the Execute message sent to finish the transaction. If the comparison fails, the communications timer in the ELU times out and the entire authority transaction is aborted.

At the ELU, the uncoded data and coded data are used to form the relevant display data stream. Each authority represents one line on the display which is formed in a 40 character buffer. Two buffers are filled using a diverse format of coded and uncoded data to form each of the abbreviated and spelled out fields for the CP number, direction and route as shown in Fig. 3.

On receipt of the execute message from the DCP, the contents of the first buffer are transferred to the cab display memory, which also echoes the message back for storage in another 40 character buffer. This buffer is then compared with the contents of the second buffer containing the diverse data. If any discrepancy exists between the contents of the display memory and the second buffer, the display is blanked and the CDU flagged as failed.

This redundancy of program paths provides extremely secure transfer of data from the DCP to the cab display memory. The final link from the display memory to the gas plasma display line is not protected by any special safeguarding. However, if an error does cause corruption of the safe line, the cognitive diversity of having both abbreviated and spelled out instructions affords a sufficient degree of fault tolerance to ensure safety.

4. CONCLUSION

This paper has shown how LIC meets the fundamental requirements for safety through the combined effectiveness of several overlapping techniques.

The LIC system breaks new ground for railway signalling systems in its complete dependence on computers and solid state devices. First, the location of trains is computed through train interrogation of wayside transponders. Second, the central computer performs the safety interlocking function. Finally, the system uses a form of cab signalling in which authorities are actually displayed in plain language to the engineman. These concepts contrast with the conventional techniques of track circuit location of trains, relay based interlocking, and fixed wayside signalling. The safety solutions in these systems have evolved over a period of time to give the expected high levels of safety.

In LIC, given that none of these old standards were available to provide safety, a fresh approach was taken that was more fundamentally suited to the nature of todays distributed intelligence systems. The essential flavour of this approach is one of both hardware and software diversity combined with well proven techniques of vital data transfer. It is likely that as operational time is accrued with the system, specification faults will be discovered which do not allow for unexpected situations. It seems inevitable then that the safety specification will undergo a period of evolution.

In conclusion, it is our belief that safety systems must use two different program versions made by two different programming teams, working independently of each other. Furthermore that implementation of each program in one of two diverse processors, each independently tested as far as possible, will greatly increase the level of safety. The probability that the two programming teams make a fault at the same functional spot in two different processors, which could lead to a dangerous situation, is inconceivably low.

With the problems of ensuring safety in computer based railway control system solved, the future is open to a wide field of operationally advanced features afforded by the flexibility of the computer. These features will provide a wealth of hitherto unavailable information and controls, such as automatic application of train brakes, train and locomotive performance monitoring, and automatic train scheduling. The realization of these features will allow future systems to provide a higher level of operational efficiency than with present systems without sacrifice to safety.

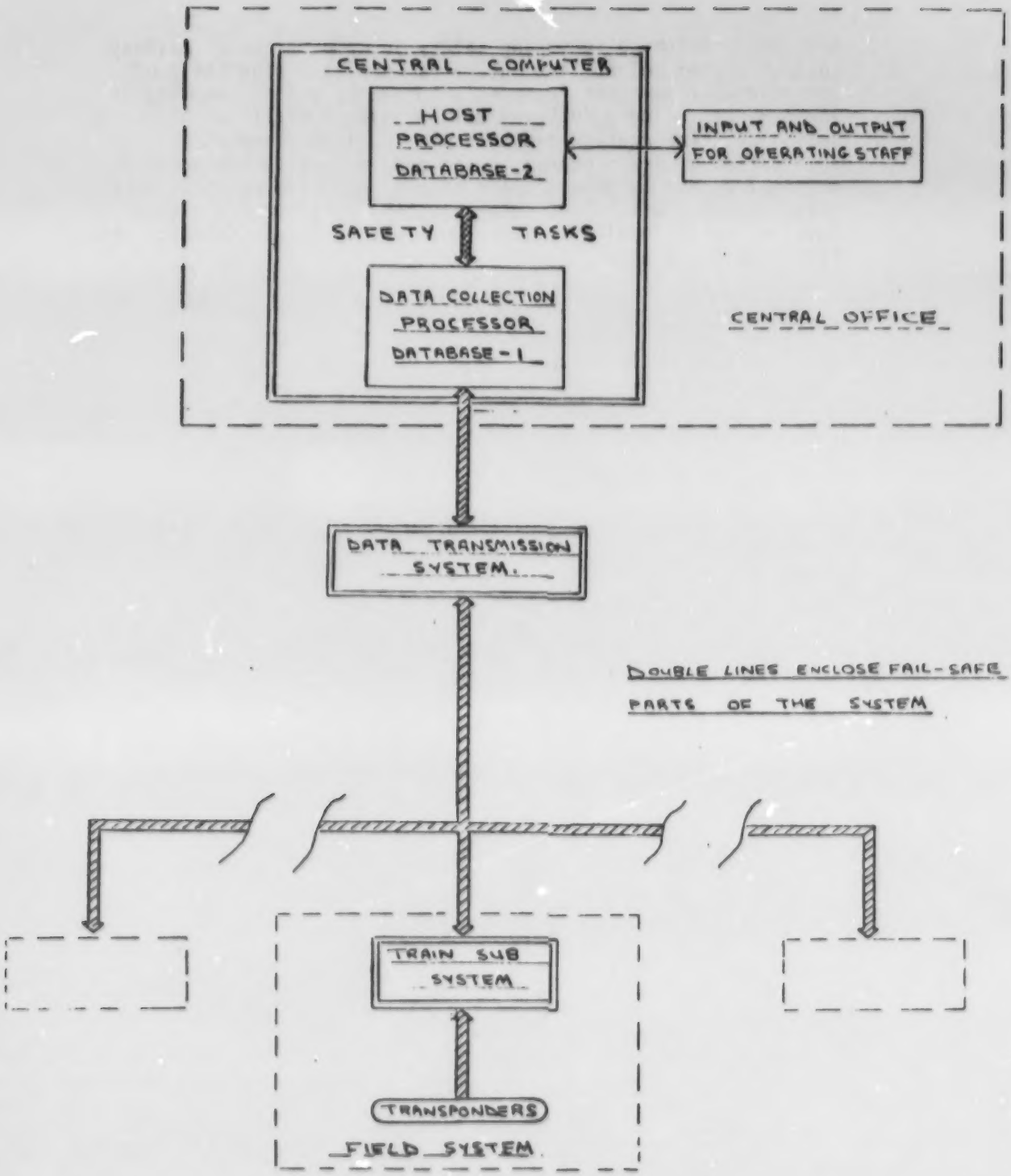

FIG 1. ASSIGNMENT OF SAFETY TASKS IN THE LIC SYSTEM

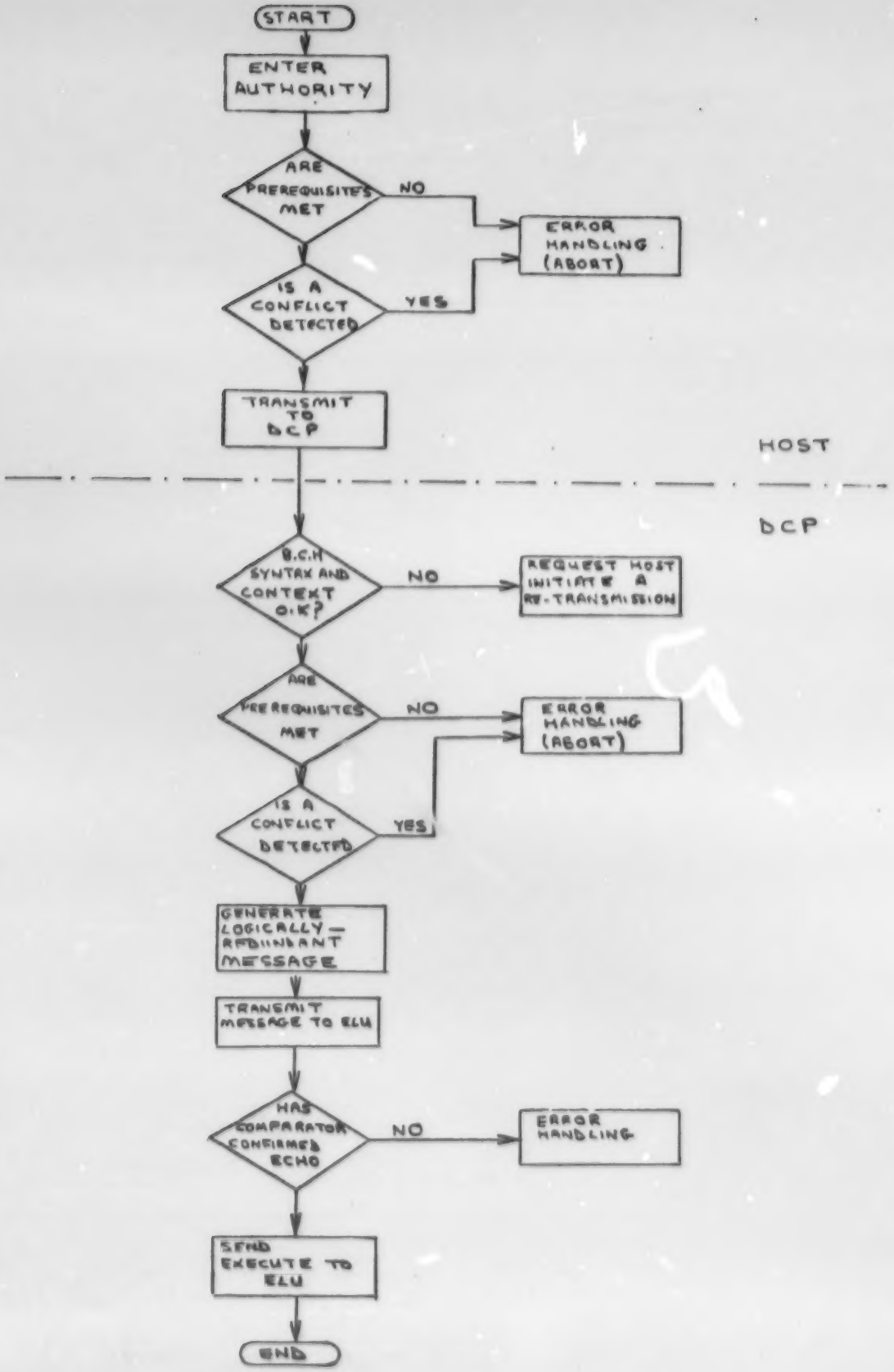

FIG 2 Fail-safe authority output sequence.

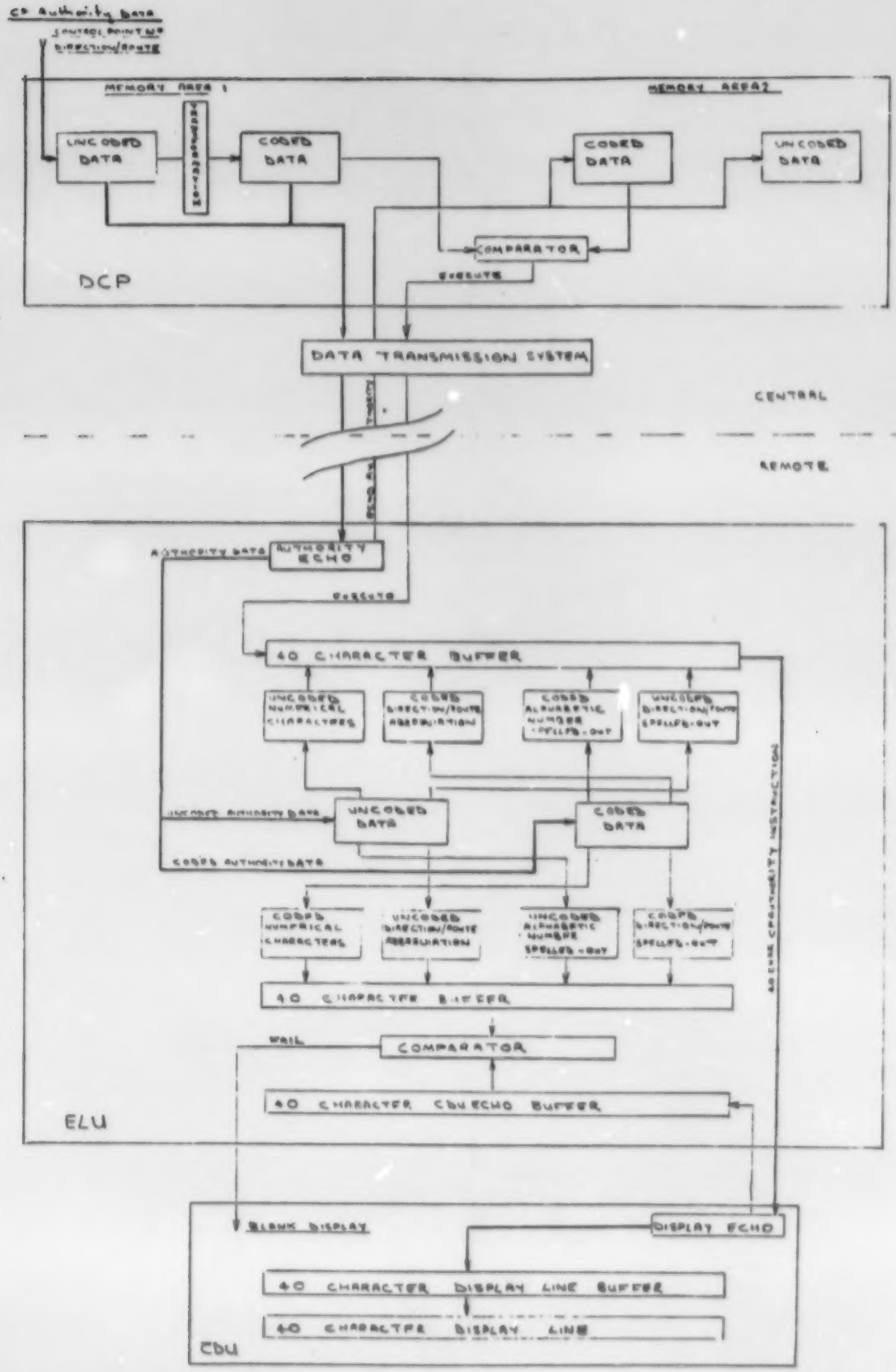

FIG 3 LOGICALLY-REDUNDANT CP AUTHORITY TRANSFER

APPENDIX 'C'

Mainline LIC Project Working Paper MWP-4

Fail Safe Techniques For Processing Systems

APPENDIX 'C'

MAINLINE LIC PROJECT WORKING PAPER MWP-4

FAIL SAFE TECHNIQUES FOR PROCESSING SYSTEMS

1. INTRODUCTION

In recent years, control system technology, such as that used in railway systems, has been strongly influenced by the advancement of electronic data processing techniques. Considerations are being made to replace the conventional fail-safe interlocking system by digital electronics which are characterized by such advantages as potential cost benefits, speed and processing, decreased size and weight, and increased accuracy. The use of processing technology, however, in the control of complex digital systems depends on the development of safeguards against the various failures involved. The importance of checking these failures and of detecting their sources cannot be stressed enough. Their presence can result in unsafe processing conditions which can, ultimately, cause deterioration of system safety.

In conjunction with this vital role of safety in systems design, a number of techniques have been developed to produce fail-safe systems. The configuration of the methods used and the application of safety design in meeting system requirements are key factors in providing effective safety. Standing alone, each method provides only partial safety. However, an effective integration of the various techniques available can produce a relatively secure level of fail-safety.

Fail-safe practices can be classified into two basic groups: hardware configuration and software procedures. However, most designs incorporate into their scheme techniques from both categories. Such a synthesis not only strengthens system safety by providing alternative means of safety-checks, but also eliminates unsafe gaps by plugging unchecked conditions with additional procedures.

The objectives of this paper are to summarize some of the safety techniques available and to examine the use of these techniques in providing safety in train control systems.

2. HARDWARE CONFIGURATION

2.1 Dual Redundancy With A Hardware Comparator

A simple hardware comparator is a physical external device which compares the output of the two processors, suppresses erroneous output and isolates the system at error detection. Except in very simple systems, application of this design has serious drawbacks. The complexity of the comparator logic must surpass that of the processor and is, therefore, unsuitable for highly integrated processing functions. In addition, some failures within the processors may not affect output and will, in such cases, remain undetected.

These problems are minimized by the use of an internal comparator. Such a device not only compares processor output but also checks data flow of the address and data bases. The comparator itself is a series of OR gates through which a flow of clock pulses is fed. An error results in blockage of the pulse and the processor is stopped. Although an improvement over its external counterpart, the internal comparator is less than perfect. The addition of clock circuitry to check data introduces the possibility of further mode failures; and, due to the synchronized operation of the two processors a burst of electrical noise may produce identical fail states in both, resulting in undetected errors.

2.2 Dual Redundancy With Self-Comparison

An alternative to providing comparison checks through a hardware comparator is to make use of the processors themselves in the comparison process. This design is based on a dual-processor system with a direct interprocessor link, redundancy management and output enabled circuitry. Both processors receive the same input data and process this data similarly, but only one device drives the output facilities. Output feedback is directed back to both processors and check data is then transmitted internally via the interprocessor link. Isolation of incorrect output is accomplished by the redundancy management and output enabled circuitry.

The two isolating components of this system (redundancy management and output enabled circuitry) can be provided as a fuse supply to the output (or to a device capable of isolating the output) which can be blown by either processor. Processor tests should be run at regular intervals to check circuit integrity.

Certain problems inherent in the hardware redundant system should be noted. The main disadvantage to such a design lies in the somewhat parallel mode in which the processors handle data. In instances where failures remain dormant for long time periods, the probability of these failures occurring simultaneously in both processors is proportional to the length of time they remain undetected. Therefore, if a fail exists in an infrequently used portion of coding sequence, it may surface at execution in both processors similarly, and a comparison of the two outputs would not detect the resulting error.

Another drawback to the 'comparator' system involves errors caused by common mode fail. Certain occurences such as systematic faults, voltage transients, noise interference and mechanical damage can produce the same error in both processors. This results in identical output contamination and the faults resulting from such fails are not checked. Various solutions have been formulated to combat such problems. They include voltage change detection circuitry, separate processor cabinet enclosures, duplicate wiring via separate routes, and coding techniques. In addition to common mode failures resulting in undetected errors, a dual redundancy system may have a complete failure shutting down one processor. As a result, comparison operations are disabled and corrupted data may be processed. Additional security can be provided by the addition of a third processor to the system.

2.3 Triple Redundancy With Self-Comparison

Triple redundancy in a self-compare mode involves a three way link between three processors. A processor detecting an unequal compare between itself and one of the other processors will attempt to disable its partner. If this attempt fails, the detecting processor will acknowledge fault and will disable itself. The main advantage of this type of redundancy is that a fail (and the subsequent disabling of one processor) will not cause a total shutdown of processing capability. The two remaining processors will continue to function, a definite advantage in a system dependent on continuing service.

It has been suggested that because the probability of two processors failing in a triple redundancy system is greater than a two processor fail in a dual system, system availability decreases as processor number increases. However, it is generally believed that the advantage of having the third "back-up" processor outweighs the increased fail probability.

2.4 Triple Redundancy With Voting System

The classical triple redundant system has recently been sophisticated by JNR (Japanese National Railway) by the addition of a voting network which plays a decision-making role in the 'compare' function. The system involves three processors, three memory modules, three majority voting restorers (MVR), a fail-safe comparator (FSC), and a fault location and mode control unit (FLU).

As data is exchanged through bases, it is voted on bit by bit and a special two bit resistor sets the compare condition. When two inputs agree the register, which is initialized at '10', shifts one bit right and then one bit left. An unequal compare results in either two shifts right or two shifts left which, in either case, removes the '1' bit from the register and indicates a fault condition.

Once an error is detected, its output is suppressed by the voting system. The MVR operates in three modes; 'voting', 'selection', and the 'and' mode. In the 'voting' mode data is made available to all three bases and in the 'selection' mode fault detection disallows data transmission in one base. The 'and' mode acts as an AND gate which is functional during the access of critical data and ensures that a double fault (one left and one right) will not occur simultaneously.

The system is backed by various physical and operational safety features. If, for example, one processor is shut down due to fault, the remaining two function as a dual system in the 'and' mode. Failure of two processors will result in output shutdown. In addition, fail-safe components are used in units and circuitry (such as the FLU, FSC and output circuits) which are involved in the compare process and which are, therefore, susceptible to undetected faults. A memory illegal access watching unit (MIW) and fail-safe watchdog timer aid in software error detection.

2.5 Single Processor With Special Safety Procedures

This method involves a single processor configuration which handles the same data in two different ways. Various software techniques, such as diversity and program redundancy, are used to supply support to this hardware system, the combination of which provides a viable example of hardware/software integration. (See following section for description of software procedures.) The advantage of using a single processor is that comparisons can be made frequently and extensively thereby providing an increased level of security. Checking can be done during processing sequence and can, therefore, detect miscalculation errors. The increased comparison frequency decreases the chance of simultaneous faults and in this way checks undetected error processing.

Unlike those designs based on hardware redundancy, parallel processing channels one set of data into two different software paths, and the probability of these paths being affected identically is very low. Common mode faults, therefore, such as electrical interference, produce different results in the two channels making the system less susceptible to the resulting errors.

The main problem with the parallel mode of processing as configured by most systems is that backup hardware is lacking. Failure, therefore, in a single processor system shuts down all processing capabilities.

3. SOFTWARE SAFETY PROCEDURES

As described by the previous sections, hardware safety systems, in themselves, are far from providing a totally fail-safe design. Additional safety support, therefore, should be obtained by the introduction of one or more software safety features into this design. These software techniques can uncover hidden, undetected errors and can check data and instructions for corruption. This section summarizes some of these procedures and indicates possible problems evolving from their use.

3.1 Input/Output Checks

I/O Checks serve to confirm input/output device functions and the validity of input/output data. Such checks are usually accomplished through processor comparisons as discussed in preceding sections. However, in cases where the state of the device changes infrequently, tests pulses may be injected to monitor its operation. Another form of I/O test involves checking the reasonability of I/O parameters (Input/Output Parameter Reasonableness Testing --IPRT/OPRT). These tests may check that a parameter lies within a certain range, increments or decrements by a prescribed value within a task or that output compares, approximately, with a secondary value derived from input.

3.2 Central Processing Unit Checks

Although most CPU checks can be accomplished by comparing data between two processors (as described in the previous section titled Hardware Redundancy), additional confirmations can be made. For example, those instructions vital to the system safety should be contained within frequently executed program segments and hardware components such as resistors, which are used in fault detection procedures, should be well exercised. Frequent use of processing elements on which safety is dependent, provides additional security in fail detection.

3.3 ROM/RAM Checks

There are a number of methods available for checking memory contents. Program integrity may be confirmed by reading ROM instructions line by line and a check made on address location of each entry. The use of checksums may be applied to RAM and ROM locations by summing data or program segments and comparing these totals with stored values.

Other check methods include the addition of check bits (or parity bits) to verify data and instructions; comparison of data with a set in secondary storage; and test patterns written into RAM to ensure that read-back is correct. The disadvantage of many of these checks is that extra RAM storage is often required.

3.4 Timing Checks

Timing checks are useful in providing additional safety support to systems operating in a dual-redundancy hardware mode with identical programs. Pulses exchanged between the two processors check the synchronization of the programs. An 'out of synch' fault will be detected if one program misses instructions or loops and protection can, therefore, be provided to the system. An additional external hardware check on processor timing may provide further security.

Timing checks can also be applied in a single program mode as seen in a procedures described as cyclic programming.

3.5 Cyclic Programming

Cyclic programming is, in essence, a type of software redundancy in that one program is executed over and over again. A check pulse can be implemented which is compared with a real time clock to ensure that each program cycle requires the same amount of time. This synchronization can be tested by ensuring that the time pulses pass through a specified time 'window' at regular intervals.

There is inherent in such a design a severe programming restriction in that program loop time must always be constant. In addition, any fault not affecting sequence timing will remain undetected.

3.6 Recovery Block Technique

The Recovery Block Technique is applicable to a system operating with a single processor especially in instances where real time execution is in use. This safety method involves a code segment which directs processing into one of two channels depending on the outcome of an acceptance test condition. A watchdog timer

monitors the time in which an acceptable result is obtained. If the acceptance test is negative or if the time expires, an alternate route is taken and another test exercised. Failures at this point results in an error return. Time resolution is set in accordance with the maximum time required for executions of that program segment.

3.7 Diversity

Diversity is a software redundant feature which treats one set of data in two or more different ways. Inverted or reversed data, for example, may be used as a comparison against original data, using programs which treat one as a function of the other. The success of software diversity hinges on the concept that failure or noise interference will affect the two data sets differently and can, therefore, be used in a single processor configuration. The parallel mode of processing is highly compatible with this type of software safety although, as noted in the section on parallel processing, the lack of backup is clearly a detriment to system availability. In view of this it may be more plausible to use diversity as a secondary safety check rather than to rely on it as a sole means of detecting system errors.

3.8 Cyclic Redundancy Check Codes

There are various error codes available for integration into software which detect errors created by noise interrupts. BCH (Bose-Chaudhuri-Hocquensham) Codes are among the most powerful of these and are based on the concept of adding check bits to information sequences, to map these and to maximize the distance between valid sequences. This distance helps to reduce errors produced from 'noise' in adjacent bits.

3.9 Data Integrity Testing

There are a series of data integrity tests which may be implemented to ensure the detection of both software and hardware errors. Some of these, such as comparison of RAM contents with backup storage and the use of checksums prior to execution have been looked at in previous sections. Data integrity can also be checked by reinitializing system tables. Contents which have been corrupted over long time periods can be, in this way, recovered.

An additional safety check can be implemented by limiting programmer access to memory, thereby eliminating possible inadvertent data changes. This can be accomplished by the use of Relocation and Bound Resistors (CDC 600 Series), Lock and Key (IBM 360 Series), Array Boundary Checks (B 5500), Paging (XDS 940) and Segmentation (Honeywell 645).

Linked data lists can be checked by the use of an end pointer to ensure list intactness, or by employing a bidirectional linked list which verifies, by comparing data from one direction with the other, that a deletion/insertion or location is valid.

3.10 Control Sequence Testing

Control sequence testing verifies proper execution of program branching and looping. The latter condition can be checked by providing an upper limit test and by supplementing this with a time-out interference.

Branching errors can be tested via a number of methods. The simplest of these involves the insertion of a second test within the branch to ensure that the correct path has been taken. Similarly, coding which involves a series of branches in a step-by-step sequence should include a final error check as an alternative route in the final branch condition.

Control points set up in the program can be used to check ranges and to control transfer. Limits placed on the range in which control can be transferred may partially check branching errors, while special codes transferred at appropriate control points can be tested for validity to ensure that program routing is correct.

Another type of branching control involves the definition of valid entry points. This can be accomplished by the use of checksums, program graphs, and Processor Sequence History (PSH) keys.

Checksums can be done on the called address and parameters and a comparison can be made between these and expected values stored in the called program section. Any discrepancies indicate that entry at that point in the sequence is unexpected.

Program graphs describe possible branching sequences and can be used to check for valid execution. One type of graph, a connectivity matrix, requires n**2 bytes (n-number of statements) and provides an ON/OFF status for entry between statements. A second type of program graph makes use of a predecessor table which describes each statement by number of possible successors and a pointer to a successor table. The successor table lists the succeeding statements, once for each possible branch leading to it.

The PSH method for controlling branching makes use of a memory check. At entry to a module, the processor searches the memory containing PSH values and compares this value with the current value using a module identification as a key. If valid, the PSH is updated and execution allowed.

3.11 Test Programs

Extremely simple programs can be software tested by using, as input, every conceivable combination of data and checking for proper execution. This method of testing, however, is not practical where instruction sets are numerous and highly integreted and, in such cases, other forms of software checks, as described in the preceeding sections, must be implemented.

Test programs can also be used to check hardware for failure conditions. These programs can be run to verify processor security and can be especially helpful in detecting errors which may surface under unique or stressful conditions.

Induced faults, by periodic test injection, can be used to identify the correct/incorrect data handling procedures in those hardware and software facilities responsible for error detection.

4. ADDITIONAL SAFETY TECHNIQUES

Routine documentation and programming procedures can provide additional support to safety systems. Well defined design rules should be followed with particular emphasis on documentation format and use. Such attention not only provides a set of standard steps through which design and programming must follow but also eliminates problems associated with subsequent system maintenance. Duplication of documentation, expecially in program coding, by different people and the creation of backup software are additional methods by which safety can be supported.

5. SAFETY METHODS AS THEY APPLY TO THE LIC PROJECT

The techniques described in the preceding text should not be considered as 'islands' of refuge from system faults. Alone, they provide some degree of safety assurance but their strength lies in the combined configuration in which they are used. The total effect of system safety involves the ability of separate fault tolerant components to function as members of an integrated safety 'machinery'.

The design of this 'machinery' requires a solid understanding not only of available safety methods but also of system safety requirements and of the design configurations used by similar applications. In aid of these objectives, the following sections will examine the current safety techniques which are incorporated into the design of the DCP unit used in the LIC (Location, Identification and Control) project, and those used in other train control systems. A comparison of the techniques used by competitors and an assessment of their reliability can be useful in establishing guidelines for acceptance or redesign of the current LIC system.

5.1 Safety As An Application Dependent Standard

Technological advances have made processor based systems available to a variety of applications, many of which differ substantially from each other in their use and safety requirements. Fault recovery time, for example, is vital to systems using real time applications. Long life applications (ie: unmanned spacecraft) require highly redundant designs to compensate for no-maintenance periods whereas applications requiring high availability (ie: time sharing) rely on techniques minimizing large scale outage.

This wide 'applications spectrum' and the varied range of requirements associated with it necessitates design descrimination in the consideration of a system. It is important to understand the particular application and its safety requirements and then to develop a safety system which will fulfill these requirements.

In addition to system requirements, cost of safety implementation and upkeep should be considered. That is, will the design cost outweigh the cost of an incurring fault. Although such comparisons are relatively straightforward in cases which merely examine safety versus maintenance, critical systems are difficult to assess in such terms. Systems in which safety is vital to lives and to overall system success require augmented safety measures as errors may evoke critical situations.

5.2 LIC System - Safety Design

The leading role of safety in the LIC System is played by diverse software. Different algorithms, held in separate memories, act on data and are the basis for comparisons which check data integrity.

The DCP transmits coded and uncoded versions of data to the ELU which echos back both of these. The uncoded version is coded with a second algorithm which is stored in a second memory. The coded echo-back is stored in yet a third memory and a comparison is made of these two coded data to confirm that the ELU received the correct message. The ELU processor uses the received data in both coded and uncoded forms to produce the cab display. This display is made up of two display forms (alphanumeric abbreviated and unabbreviated) to verify the instruction. In addition, this display message is recreated in a second buffer using an alternative coding combination.

A dual-host/dual-DCP configuration is proposed for the system. The second Host-DCP 'pair' act as backup in the case of a failure. The backup pair do not receive ELU input, only partial updating data to the data base and are solely for backup use.

The LIC system configuration, then, is basically designed in a single processor mode which uses diversity to check data and includes backup hardware.

6. OTHER SYSTEMS

In comparison to LIC, many other similarly applied systems are more hardware oriented in their safety design. Of the five studied, four systems use some form of comparing either via a hardware comparator or by intra-processing checking. In all cases, additional security is provided by software applications.

Table 1 summarizes the use of various safety techniques as they apply to current control systems. This table is only an indication of the main safety elements in system design and is not a complete portrayal of each system's configuration. The following sections provide a brief description of the various train control systems with respect to system safety.

TABLE 1

SYSTEM	Hardware Compare	Self Compare	Triple Redundant	Triple with Voting	Parallel Process	I/O Checks	CPU Checks	Memory Checks	Timing Checks	Cyclic Program	Recovery Block	Dynamic	BCH Codes	Data Interface	Control Sequence	Techniq.	Additional
LIC	-	-	-	-	X	-	-	X	-	-	-	X	X	X	-	-	X
BR	-	-	X	*	-								X				
GRS	-	-	-	-	-				X			X		X		X	
SIMIS	X	-	-	-	-		X	X				-				X	X
ERICSSON	X	-	-	-	X							X			X		X
JNR	-	-	*	X	-												X

KEY: X technique used
- technique not used
* some aspects of technique used not indicated as used/not used

TABLE 1 - Safety Techniques in Current Railway Control Systems

6.1 British Railways

The safety design employed by British Rail involves a triple redundant mode, with three processors, three communication processors and two data link modules which access the duplicated data link. A combination of reliability and availability is the objective of this design.

Incoming and outgoing data is coded and decoded by the communication processors and is then voted on via the three interlocking processors. Additional safety is provided by interprocessing links which verify processor contents. The data link and is associated modules are in dual mode to provide security and availability and a second panel processor, which links to the panel, is used as backup hardware.

The software used in configuration with the 'triplicate' British Rail system is not specifically defined, although its importance is obviously recognized by British Railways in completing system safety. Coding is done in assembler language due to the 'uncertainty' of high level compiler 'behaviour'. Striving for highly reliable software as opposed to that with great diversity seems to be the objective of British Rail's software team.

6.2 Japanese National Railway

A detailed description of Japanese National Railway's hardware configuration, in the application of safety, is given in the section headed, "Triple Redundancy With Voting System". Basically the Japanese and British systems are alike in that they both use triple processors which exchange and compare data. Japanese National Railway uses a triplicated voting system to check this data. Each of the three voters receive input from all three processors and vote on the information bit by bit. Modular programming is used to provide high reliability and universally usable software.

6.3 SIMIS (By Siemens)

SIMIS is a dual-redundant fault tolerant microcomputer system developed by the German corporation of Siemens. A comparator checks data consistency between two processors and within the data base and a clock pulse serves as an indicator of segment boundaries in these comparisons. Error detection results in the inhibition of this pulse, signifying a fault condition. When a fail state has been declared, the switching circuits are de-energized by the output signal converter which is connected to the comparator.

The SIMIS system is based on the use of established fail-safe elements of which failure modes are thoroughly understood. However, there are problems associated with the use of these components in control systems (as suggested by Siemens themselves) such as requirements for clock synchronization, dependence on the comparator and signal converters and the omission of self-checking circuitry. The lack of backup hardware is also a problem since a fault condition will delay processing and will, therefore, suspend system safety.

6.4 Ericsson

L. M. Ericsoon of Stockholm have developed a computer system specifically for use in railway traffic control. The design is based on the concept that software diversity is the only secure solution to possible systematic component fails.

A single computer, divided into two subsystems, makes up the main hardware and acts as the compare point of two sets of data input. Identical data, of two distinct forms, is created by the use of diverse software. Inversion, reversal (etc.) of one data set is performed early in the processing cycle and the resulting version is compared with the original. The converted data is held in a separate memory and the comparison is made within the CPU. This system allows extensive comparisons and may detect errors in infrequently used segments of coding.

Software diversity, the vital component in the system, is accomplished by the use of separate programming teams. In addition, programmed control points ensure that program run-through is complete.

The main flaw in the design is the lack of backup procedure in case of a system fail. At error detection an alarm is set and output is restricted, resulting in the virtual shut-down of system availability. The addition of a backup unit to the basic configuration, as developed by Siemens, would provide increased security.

6.5 General Railway Signal

Safety Assurance Logic is a processor based design developed by General Railway Signal and is described in a separate section under "Software Safety Procedures". In essence the system relies on the provision of safety to each of its individual elements and on the verification of component integrity through repetitive testing procedures. Cycle checks, diversity, ROM/RAM checks are a few of the types of software techniques implemented in this design. Processor performance is measured against a standard (ie: check word table) which is itself checked for integrity.

7. CONCLUSION

The design of a fail-safe system requires careful consideration in the areas of application requirements, cost feasibility and the integration of safety techniques. No ONE method can overcome all possible fail modes, and the type of faults within a system which will activate a critical condition will vary from one application to another. It is essential, therefore, to realize the limitations of each safety procedure and to back up unsafe processing routines by additional security.

For those control-type applications currently in use, hardware redundancy has been the main mode of providing fail-safety to a system. The principle flaws in hardware redundant designs are the processing of common mode failures and the identical manner in which data is handled resulting in two common faults. In systems which are susceptible to such faults, frequent testing and provisions against common mode failures should be made.

The second major problem in safety development is exemplified by the systems designed by Siemens and Ericsson. Both configurtions lack backup protection. In cases where dual redundant or parallel processing modes are being contemplated, additional hardware for backup purposes should be considered.

The triple redundant mode, when feasible, provides a viable alternative to a 'dual-with-backup' configuration. A three processor design not only provides a three way check on data but also ensures backup availability.

Regardless of what hardware configuration is used to provide fail-safety, software techniques should be incorporated into safety design. Many hardware modes are restrictive in their checks and leave 'holes' through which errors can escape unnoticed (ie: hardware comparator only checks errors affecting output). The 'plugging' of these holes is essential in creating an 'error-tight' design and can be accomplished via many software safety methods.

The configuration of a well integrated hardware-software design is a major step forward in creating a safe system. However, additional safety features should be included to check those portions of the system relating specifically to safety. Registers and program segments, for example, involved in safety checks should be used frequently in program execution and test runs of such safety elements should be continually implemented.

The final design provisions in creating a fail-safe system, as illustrated by most of the applications studied, is the use of proper documentation, reliable programming, and extensive testing. Many programming techniques can be specifically applied to provide additional safety such as loop and branch checks and program access. Testing is useful not only in the detection of system faults but also in uncovering dormant errors.

Once the safety requirements of a system have been established a design can be created which best fulfills the needs of its particular application. Relevant information with respect to attaining safety can be gained by studying similar applications and by a total awareness of available safety techniques - their advantages and disadvantages. A well implemented integration of these varied safety procedures is the final step in creating maximum security in system safety.

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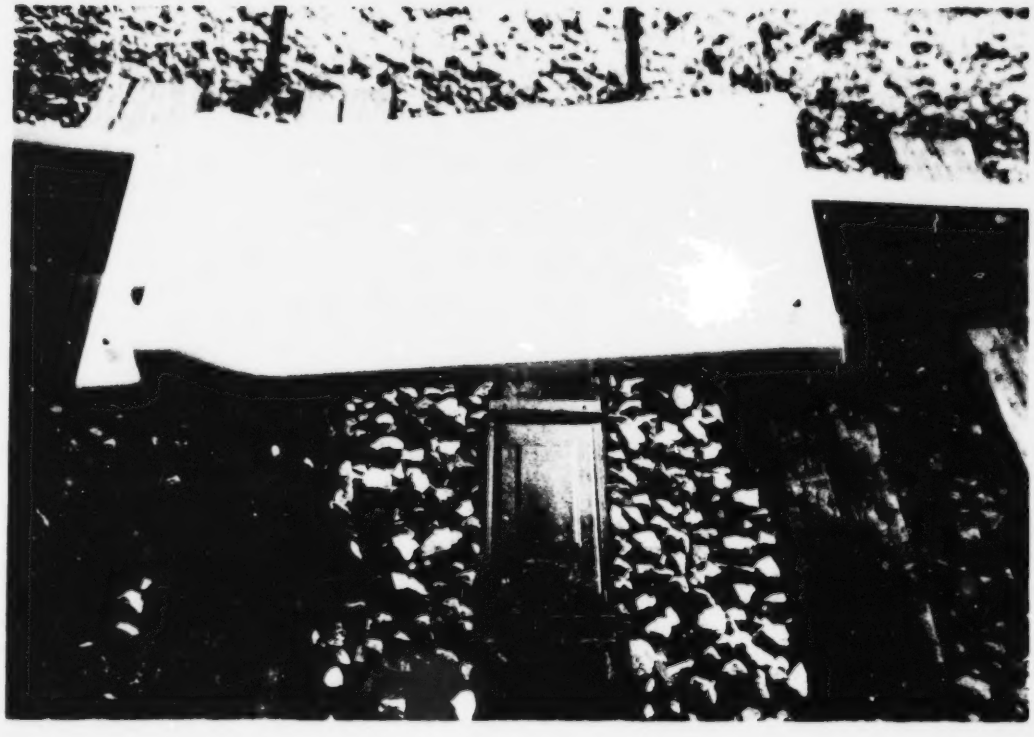
APPENDIX 'D'

Glenayre GL6000 DIGITRAC System Product Description

GL 6000

DIGITRAC SYSTEM

Glenayre electronics



GENERAL DESCRIPTION

The DIGITRAC system provides data transfer between moving vehicles and the wayside. The transfer occurs at fixed locations precisely defined by the position of the equipment.

The system comprises three units:
the transponder, interrogator, and controller. Each unit is ruggedly constructed to withstand the extremes of temperature, weather, and vibration encountered in the transportation environment.

The equipment has been designed for flexibility of use and can readily be interfaced to various display, recording, or processing equipment.

Applications include vehicle location, electronic sentry, vehicle identification, route control, and trip recording. Powerful data acquisition techniques assure reliable and secure data transfer at vehicle speeds from zero to over 100 mph.

FEATURES

- *Vehicle-to-Wayside or Wayside-to-Vehicle applications*
- *Four-digit, highly secure data transfer*
- *Reliable solid-state circuitry*
- *High performance micro-computer controller*
- *Hermetically sealed transponder*
- *Serial asynchronous output at 300 to 9600 Baud*
- *RS232-compatible interface*
- *FCC approved for unlicenced operation*

TECHNICAL DESCRIPTION

the DIGITRAC Controller comprises three major circuit elements; the power supply, the RF receiver, and the digital processor.

The power supply for on-vehicle installations is a modified flyback DC-DC converter. Featured in this circuit are: reverse polarity, high voltage and transient protection, single fuse components protection in case of short circuits, and output regulation. It is suitable for direct connection to locomotive 72 VDC supply. For wayside installations a 110 VAC line input power supply is provided.

The rf section receives and demodulates the transponder data signal.

The digital processor is a micro-computer based circuit which demodulates the DPSK sub-carrier, locks onto the reference frequency, monitors for interrogator failure, creates a synchronous data clock, analyses burst transponder data to validate transponder numbers, and provides an external serial output interface via a RS232 port to the outside world. An LSI USART is used to generate serial asynchronous character data output under the control of the micro-computer.

The DIGITRAC Interrogator generates a 200 KHz electromagnetic field. This electromagnetic field is strong enough in the vicinity of the interrogator field (10 to 24 inches separation) to energize the passive transponder by inductive coupling. The interrogator also provides antenna circuitry to receive the HF transmission from the transponder, as well as interface circuitry to the transponder reader for power, frequency reference and RF data.

The DIGITRAC Transponder is an inductively powered data source. Its circuitry can be divided into four sub-elements. The 200 KHz power receiver, the logic data generator, the DPSK synthesizer, and the HF transmitter.

The 200 KHz power receiver inductively receives the electromagnetic radiation from the interrogator and utilizes this to provide a frequency reference for the logic circuitry and, after rectification and filtering, to provide the DC supply voltage to power the transponder.

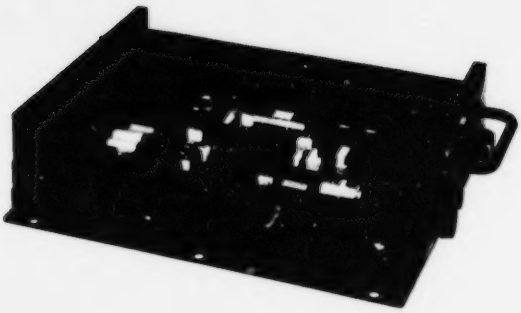
The logic data circuit generates a 4 decimal digit serial code at a continuous rate using the 200 KHz interrogator frequency as a clock reference. Thus ten thousand highly secure codes can be generated for a wide range of applications.The serial binary data stream is then fed into the DPSK synthesizer for modulation.

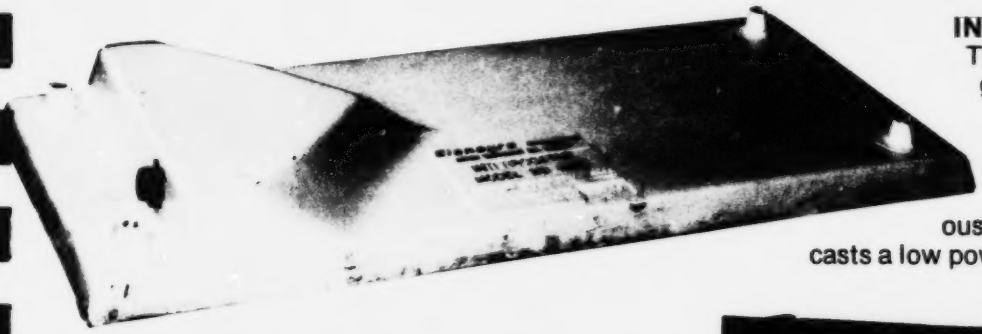
The DPSK synthesizer circuitry generates a 25 KHz sinewave data carrier and differentially shift keys the phase of the logic generator. The information is then fed to the RF stage for transmitting.

The RF transmitter uses a third overtone quartz crystal oscillator to ensure accurate, stable operation throughout an operating temperature range of -40°C to +70°C (-40°F to +158°F). The transmitter will continuously send the transponders' identification data as long as the transponder remains within the electromagnetic field of the interrogator. Accurate data transfer is obtainable from the DIGITRAC transponder at vehicle speeds from zero to well over 100 mph.

The design of our DIGITRAC system permits custom features such as multiple number storage and advanced number interpretation in the reader itself.

DIGITRAC CONTROLLER
The DIGITRAC Controller is a microcomputer-based data acquisition and control unit. It interfaces to vehicle power directly and also supplies power to the interrogator unit. Transponder data signals are demodulated in the reader and checked for integrity. After data verification, the validated transponder number is available at the reader output interface.

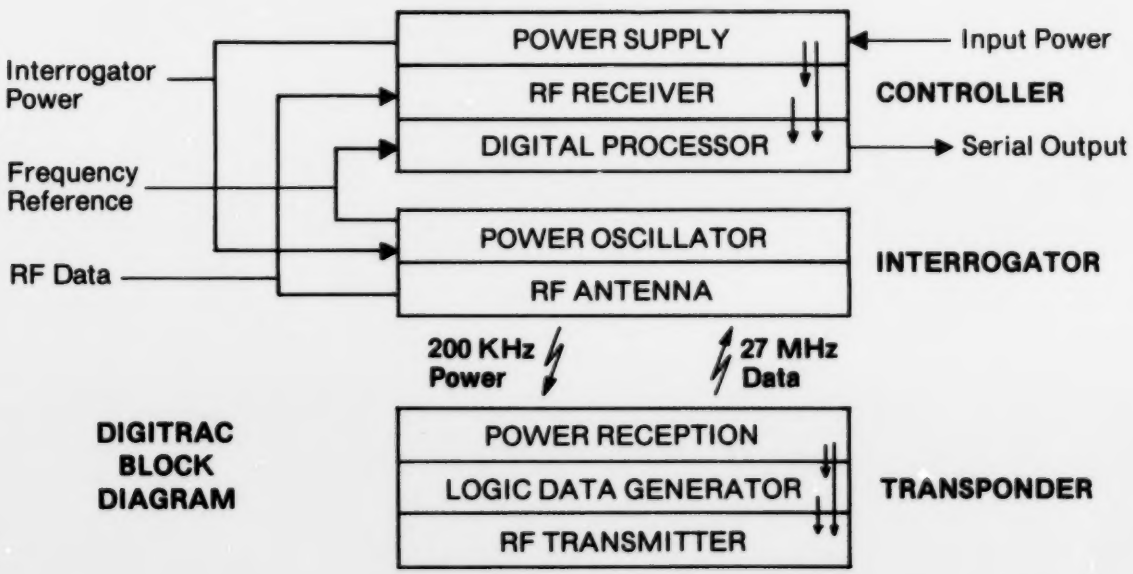




INTERROGATOR
The DIGITRAC interrogator is a hermetically sealed unit which is normally mounted on the underside of the vehicle. It continuously generates and broadcasts a low power electromagnetic field.

TRANSPONDER
The DIGITRAC transponder is a small hermetically sealed unit which is normally mounted on the wayside roadbed at fixed point location. When inductively energized the transponder will transmit a four fixed decimal digit data pulse. BCH error check security techniques protect all transmitted data to ensure accuracy.

Note that the controller and interrogator may alternatively be mounted at the wayside with transponders on the vehicles, for vehicle tracking applications. In this configuration a real-time clock is incorporated in the Controller.



DIGITRAC BLOCK DIAGRAM

SPECIFICATIONS

Transponder — Model 6110

Number of digits	4 decimal
Number of selection	Fixed at time of manufacture (external selection optional)
Power requirements	Powered by inductive coupling with Interrogator.
Operating Distance	25 cms to 61 cms (10 in. to 24 in.)
Temperature	-40°C to +70°C
Environment	Unaffected by snow, ice, dirt, water. May be fully immersed.
Dimensions	38 x 20 x 2 cm (15 x 8 x ¾ in.)
Weight	1.4 kg. (3 lbs)

Interrogator Coil Unit (ICU) — Model 6215

Connections	Input power and received data through single MS-type connector.
Distance from Controller	Up to 30 meters (100 ft)
Temperature	-40°C to +60°C
Environment	Unaffected by snow, ice, dirt, water. No conducting screen may be placed between the ICU and the transponder. The ICU must be at least 15 cms (6 inches) from any conducting surface.
Dimensions	86 x 39 x 8 cms (34 x 15 x 3 in.)
Weight	6.8 kg (15 lbs)

Controller — Model 6502

Power required	Less than ½ amp at 72 vdc
Output Interface	RS232 compatible serial asynchronous
Temperature	-18°C to +55°C
Environment	Suitable for the physical and electrical environment of a locomotive.
Dimensions	41 x 29 x 9 cms (16 x 11.5 x 3.5 in.)
Weight	5.5 kg (12 lbs)

Glenayre reserves the right to modify or change the design, manufacture or specifications.

REPRESENTED BY:

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APPENDIX 'E'

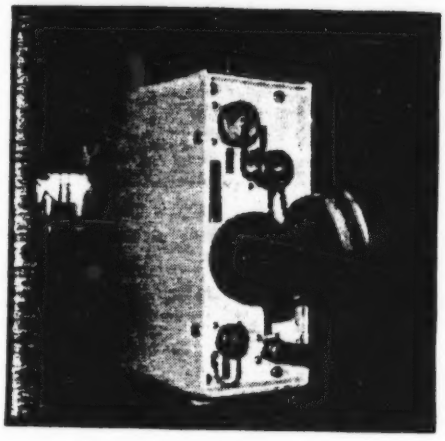
Glenayre GL6535 DIGITAIR System Product Description

NEW PRODUCT

6535
DIGITAIR

Railway Brake Pressure Monitor

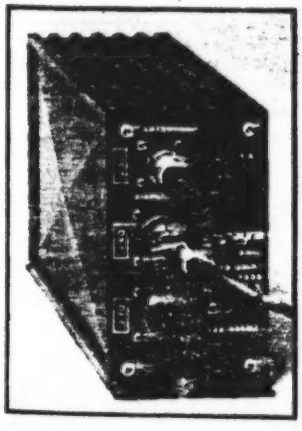
Glenayre electronics



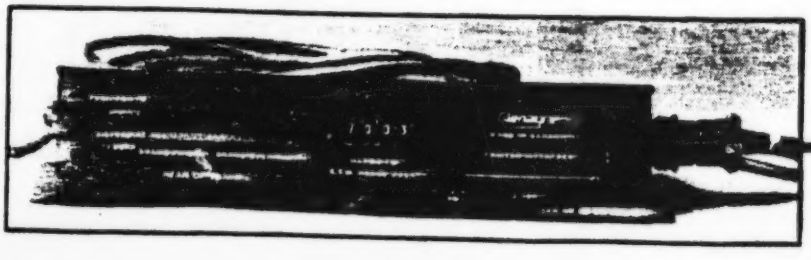
6531
Sense & Transmitter Unit

DIGITAIR gives the engineman the ability to continuously observe his brake pipe air pressure as measured at the end of the last car of his train. A sense and transmitter unit is mounted on the coupling knuckle at the rear of the last car, and is connected to the brake pipe by a standard AAR "Glad-Hand" coupling. Brake pipe air pressure is sent by VHF radio to the locomotive receiver and is displayed on the engineman's Remote Display Unit.

The experienced engineman will immediately realize the benefits of having the easy-to-read "DIGITAIR" display available to him, especially when handling long trains. Advantages may be recognized in obtaining instant indications of rear-of-train brake pipe pressures during system charging, when handling slack, and as an aid to judging the effects of automatic brake valve pressure reductions.



6532 Receiver



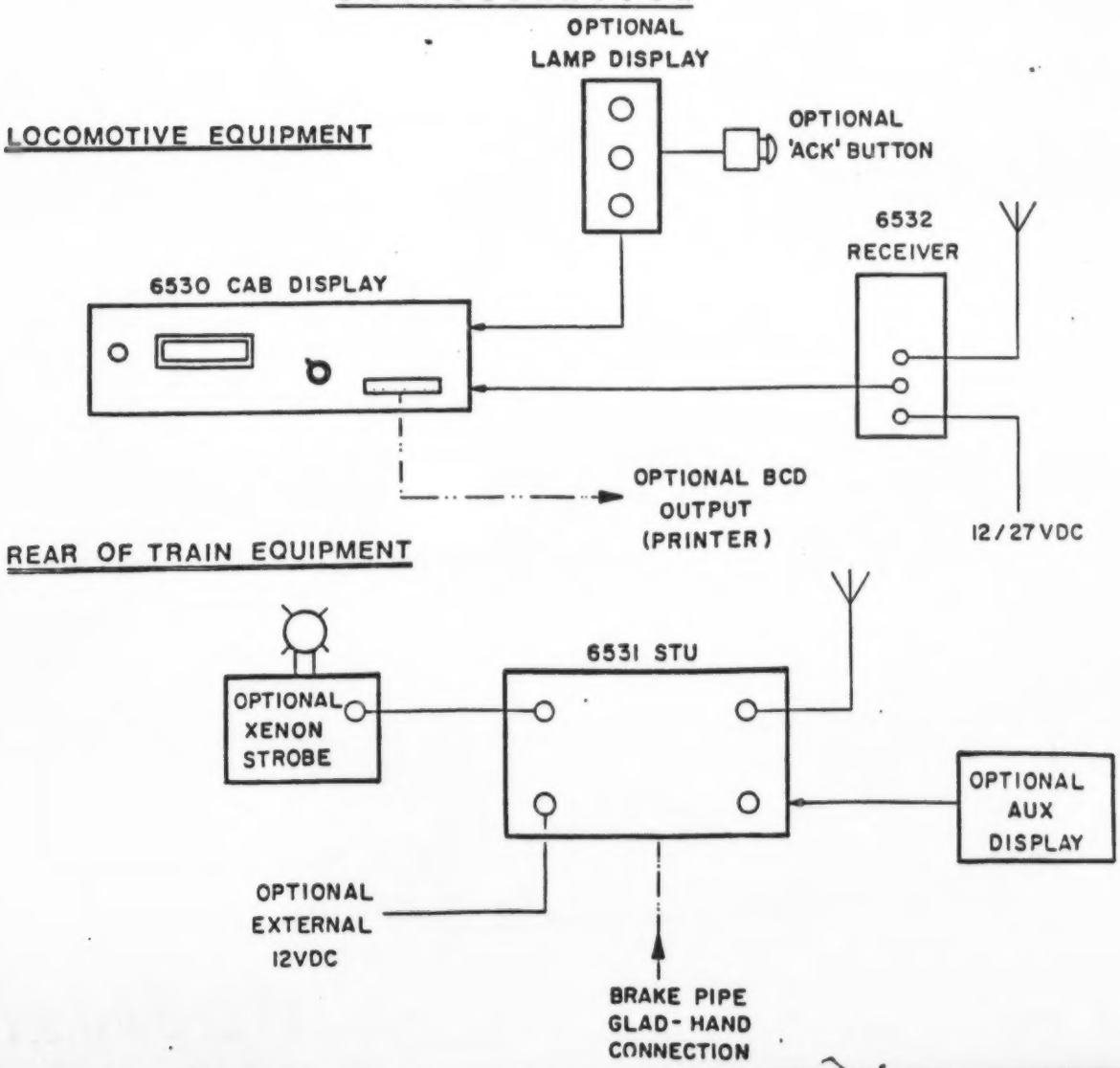
6530 Remote Display Unit

PRELIMINARY

AVAILABLE OPTIONS

- Simultaneous cab display of two pressures (e.g. last car brake pipe pressure and auxiliary reservoir or brake cylinder pressure).
- Separate lamp display. - Mounts three wide angle lamps which are activated at pre-set pressures. Push button acknowledgement cancels audible alert.
- Auxiliary digital display - Plugs into rear mounted unit with extension cable.
- Rear of train xenon strobe light - Automatically activated by low ambient light. DIGITAIR monitors strobe operation and signals operating status and failure alarm to engineman.
- BCD data port provides interface for printer or customer's other locomotive mounted data collection systems.

CONFIGURATION



APPENDIX 'F'

Radio Switch Control Unit (RSCU)
Functional Description and Specification
(Issue 3, February, 1983)

1. SCOPE

1.1 Introduction

Radio Switch Control Units (RSCUs) are to be operated in conjunction with the GLENAYRE Location, Identification and Control (LIC) system of train control. The latter assists the dispatcher at a Central Control Location (hereafter referred to as "Central") in controlling and monitoring train movement by radio communication. The addition of Radio Switch Control Units to the LIC system enables the dispatcher to set and monitor switches from his Central location, thereby increasing the efficiency of train movement. Central communicates with the switch units in the same way as it does with locomotive logic, polling each RSCU by name and obtaining status. Another message is used to change the switch setting, and a secure "hand-shake" procedure ensures correspondence between the switch position and the computer-stored status.

1.2 The RSCU-Functional Description

The RSCU provides remote control and monitor of conventional railroad switches. This is done through a radio link between wayside switch control logic and Central. In addition to a secure radio link, the control logic provides interlocking between a switch occupancy relay and the activating motor. This feature prevents the switch from being thrown under a train. The RSCU is designed for use with various power control switches (Section 2, documents 2.4, 2.5).

Two RSCU modes of operation are defined:

1. Interrogation, whereby the RSCU replies to a status request message from Central. The reply indications include switch position (Normal, Reverse or out of correspondence) and switch occupancy information (occupied/unoccupied).

2. Controls, in which the RSCU responds to an instruction from Central to change the position of the switch points.

A functional RSCU block diagram is given in Figure 1.

2. APPLICABLE DOCUMENTS

2.1 "Location, Identification and Control Project - Specifications", June 1976.

2.2 "American Railway Signalling, Principles and Practices", by AAR, Communication and Signal Section:

1. Chapter 6: Direct Current Relays (1966)
2. Chapter 7: Non-Coded D. C. Track Circuits (1948)
3. Chapter 11: Non-Coded A. C. Track Circuits (1951)
4. Chapter 20: Interlocking Circuits (1941)
5. Chapter 25: Coded Track Circuits (1959)
6. Chapter 26: Relay Interlocking (1961)
7. Chapter 29: Electric Interlocking (1950)

2.3 "CN Signal Training" - Volume 2, chapters 1 and 8.

2.4 "GRS Models 5E, F, G, and H Electric Switch Machines - Installation and Maintenance Manual".

2.5 WABCO Ltd.: "M-3, M23A, and M-23B - Installation and Maintenance Manual".

2.6 GLENAYRE Drawing MTD 6300-1: Timing Diagram for System Data Conversion and Recovery (All except for item 10, since AM mod is not used).

3. REQUIREMENTS

3.1 Functions

The RSCU assumes the following functions:-

a) Receives and transmits DPSK data, as in document 2.6.

Data rates : 300 baud nominal, strappable to 150, 600, 1200 baud.
Modulation: DPSK

b) Demodulates and decodes incoming signals and recognizes messages from the selective call block.

c) Detects Coding and Context errors in incoming messages, see d).

d) Replies to valid messages from Central:

1) Echo reply to Central instruction,
2) Status reply to Central status request,
3) Context reply to commands given in a wrong context, such as: a switch throw command when the switch is unlocked.*

*Note: a switch is considered "unlocked", when the switch position relays show neither normal nor reverse position.

e) Upon Central instruction, actuates the switch.

f) Upon Central status reports, interrogates the switch.

3.2 Power

The RSCU utilizes power normally available at power switch locations. It converts and regulates this power to operate the radio unit, the logic circuitry, the switch control and monitor interfaces.

Required Power:

	24 VDC	8 Amp
or	110 VDC	2 Amp
or	115 VDC	2.5 Amp
or	230 VDC	1.25 Amp

3.3 Environmental Requirements

The RSCU is to be operated in the field. It has to withstand extreme and adverse weather and environmental conditions. It is specified as follows:-

Operating Temperature:	-40 degrees C. to +60 degrees C.
Storage Temperature:	-55 degrees C. to +80 degrees C.
Enclosure:	In a rugged heavy box, with cables interfacing to switch machine and track circuit relay contacts. The enclosure will conform to AAR standards.

3.4 Data Specifications

Data Rates: standard: 300 baud
optional: 150, 600, 1200 baud (strappable)

Incoming and outgoing data are organized into 10 bit groups: one Start bit, 8 Information bits and one Stop bit. Data are transmitted in a serial form, asynchronously. The serial transmission is least significant bit first, to conform with standard UART configurations.

Messages consist of 4 character blocks: 3 are information characters and one is a block check character. The check character consists of: 1 end bit (signifying last block, if high), 1 start bit (signifying first block, if high), 5 BCH (31, 26) code bits and one odd parity bit.

DPSK modulation is used to minimize communications error probabilities. The use of a BCH and parity coding system maximizes error detection probabilities.

3.5 Message Types and Structure

The RSCU recognizes five types of messages from Central:-

1. Status request:

   Central requires information about switch position and occupancy status.

2. Normal Throw Command:

   Central commands to throw the switch to normal position.

3. Reverse Throw Command:

   Central commands to throw the switch to reverse position.

4. Normal Override:

   Central commands to throw the switch to normal position, in spite of it being out of correspondence or having failed.

5. Reverse Override:

   Central commands to throw the switch to reverse position, in spite of it being out of correspondence or having failed.

The RSCU responds with one of the following replies:-

1. Status: reporting switch and track status.
2. Echo: confirming command.
3. Context: reporting a command given in the wrong context, (see 3.5.6).

The first block of each message (incoming and outgoing) consists of:

1st Character: Message Code
2nd Character: RSCU I.D. Number-Least Significant Digits. (ID.0)
3rd Character: RSCU I.D. Number-Most Significant Digits. (ID.0)
4th Character: Block check character (BCC)

Message Codes (in hexadecimal) are as follows:-

Central ----- RSCU		RSCU ---- Central	
(11)	= Status Request	(91)	= Status Request
(12)	= Normal Throw	(92)	= Echo Normal Throw
(13)	= Reverse Throw	(93)	= Echo Reverse Throw
(14)	= Normal Override	(94)	= Echo Normal Override
(15)	= Reverse Override	(95)	= Echo Reverse Override
		(D1)	= Context Error

3.5.1 Request Interaction

Status Request is a single block message, as described below:-

0	0	0	1	0	0	0	1
RSCU NUMBER, L.S.D.'s (ID.0)							
RSCU NUMBER, M.S.D.'s (ID.1)							
BLOCK CHECK CHARACTER (BCC)							

The addressed RSCU (having an I.D. # identical to the one in characters 2 & 3) responds by a Status Report: this is a two block reply. The first character of the second block includes the status information.

1	0	0	1	0	0	0	1
ID.0							
ID.1							
BCC							

STATUS
SPARE
SPARE
BCC

The status bits are as follows:-

Bit	Function
1	Switch failed
2	Switch out of correspondence
3-5	Unused
6	Switch track set occupied
7	Switch in reverse position
8	Switch in normal position

1	2	3	4	5	6	7	8

Bit Numbers

3.5.2 Normal Throw Command Interaction

This command comes as a one block message from Central to the RSCU, as follows:-

0	0	0	1	0	0	1	0
ID.0							
ID.1							
BCC							

The RSCU addressed by this message responds in one of the following ways:-

1. If everything is correct, the RSCU:-

   a) replies with an Echo Normal Throw message to Central, to confirm everything is correct.

1	0	0	1	0	0	1	0
ID.0							
ID.1							
BCC							

   b) activates the control relay which enables Normal switch throw.

2. Context reply if:

   a) the switch is out of correspondence
   b) the switch is already in the normal position, or
   c) the track is occupied, or
   d) the switch failed, or
   e) a switch throw is in progress.

3.5.3 Reverse Throw Command Interaction

This command comes as a one block message from Central to the RSCU:

0	0	0	1	0	0	1	1
ID.0							
ID.1							
BCC							

The RSCU addressed by this message responds in a similar manner to the one described in section 3.5.2. If everything is correct, then:

a) an Echo Reverse Throw message is sent to Central:

1	0	0	1	0	0	1	1
ID.0							
ID.1							
BCC							

b) the RSCU activates the control relay which enables Reverse switch throw.

3.5.4 Normal Override Interaction

This command activates the switch even if it is out of correspondence or a failure condition has been declared. It comes as a one block message from Central to the RSCU:

0	0	0	1	0	1	0	0
ID.0							
ID.1							
BCC							

1. If everything is correct, the RSCU responds by:

   a. an echo reply to Central

1	0	0	1	0	1	0	0
ID.0							
ID.1							
BCC							

   b. throwing the switch to normal position.

2. A context reply results from:

   a. a switch already in the normal position
   b. a switch throw action is in progress
   c. an occupied switch

3.5.5 Reverse Override Command

This command comes as a one block message from Central:

0	0	0	1	0	1	0	1
ID.0							
ID.1							
BCC							

1. If everything is correct, the RSCU responds by:

   a. an echo reply to Central.

1	0	0	1	0	1	0	1
ID.0							
ID.1							
BCC							

   b. a switch throw to reverse position

2. A context reply results from:

   a. the switch already being in the reverse position
   b. a switch throw action is in progress
   c. an occupied switch

3.5.6 Context Replies

If a switch throw command is received in a wrong context, the RSCU replies with a context message.

1	1	0	1	0	0	0	1
ID.0							
ID.1							
BCC							

CONTEXT FLAGS
SPARE
SPARE
BCC

Context flags are the same as the switch status bits (sec. 3.5.1) and are to be analyzed at Central.

3.6 Interfaces

Typical existing switch control and monitor circuits are shown in Figures 2 and 3. The RSCU interfaces to these circuits in the following manner:

3.6.1 Switch Monitor Interface

In reference to Figure 2, the RSCU detects switch position by monitoring the contacts of switch position repeater relays, NWPR and RWPR. Closure of NWPR contacts indicates the switch being in normal position. Closure of RWPR contacts indicates the switch being in reverse position.

3.6.2 Switch Control Interface

In reference to Figure 3, the switch control relay/s (WZR) are interfaced to and controlled by the RSCU. Positive energy supplied to WZR and LR throws the switch to Normal position. Negative energy to WZR and positive energy to LR throws the switch to reverse position. No energy to LR results in the switch electric control being de-activated. Existing relay-logic interlocking in the switch unit is not altered.

3.6.3 Track Occupancy Relay Interface

The RSCU interfaces to track circuit occupancy relay contacts, and thus detects track occupancy status.

3.7 Radio

The radio unit is a UHF receiver-transmitter with a quarter wavelength antenna.

Modulation Frequency	:	468 MHz (DPSK : to 1200 baud)
Modulation	:	FM
Input Minimum Signal to Noise Ratio	:	5 db
Maximum Current Drain	:	8 Amp
Transmitter Power	:	10 - 15 watts
Input Impedance	:	50 ohms

3.8 Safety Considerations

a) No safety feature in the existing switch control circuits is sacrificed. Interlocking between track circuits and switch movements are retained. Therefore, existing control logic is to be utilized.

b) Occupancy relays are to be interfaced to the RSCU and thereby interlocked to the switch, conforming to AAR standards (Documents 2.2.2 - 2.2.7).

c) DPSK modulation and block check coding is utilized to minimize the occurrence and effects of communications errors and thus, establish a secure radio link between the RSCU and Central.

d) Regular communication between the RSCU and central is maintained. Should the RSCU fail to reply to messages from central a failure alarm is raised.

e) Each RSCU is identified by a unique identification number. The high data security provided by the block check code prevents the wrong switch from being addressed.

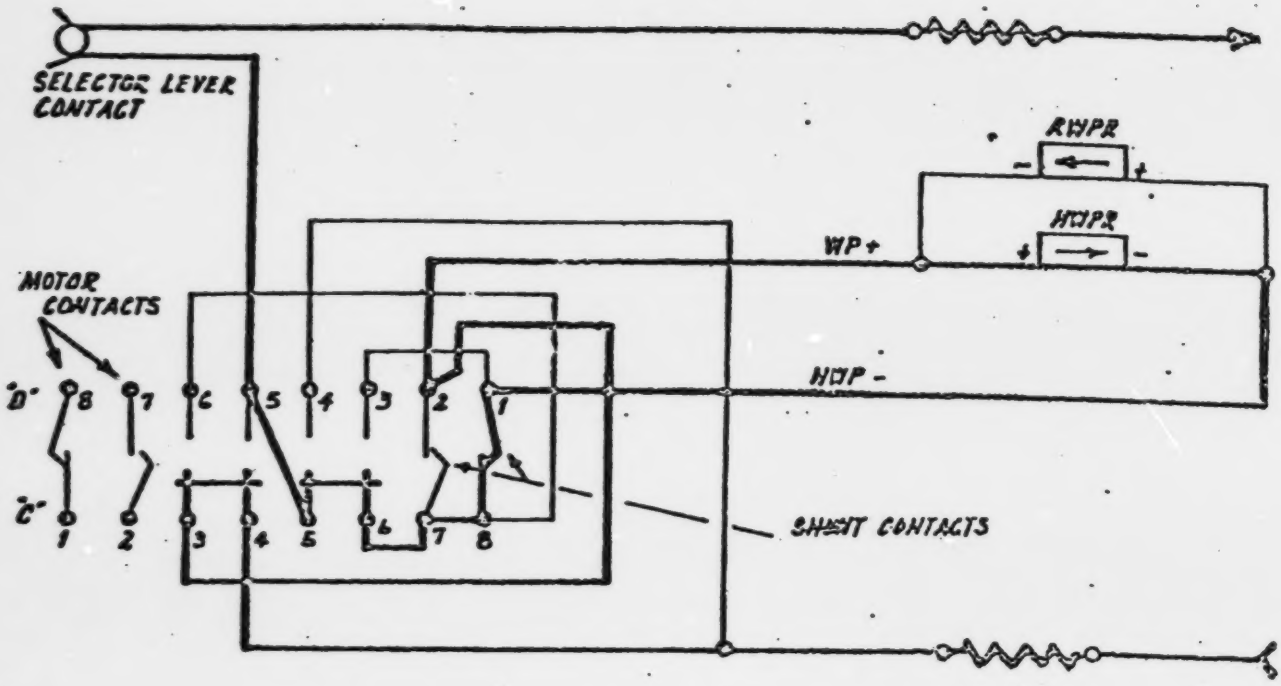


FIGURE 2. GRS MODEL 5D - INDICATION CIRCUITS

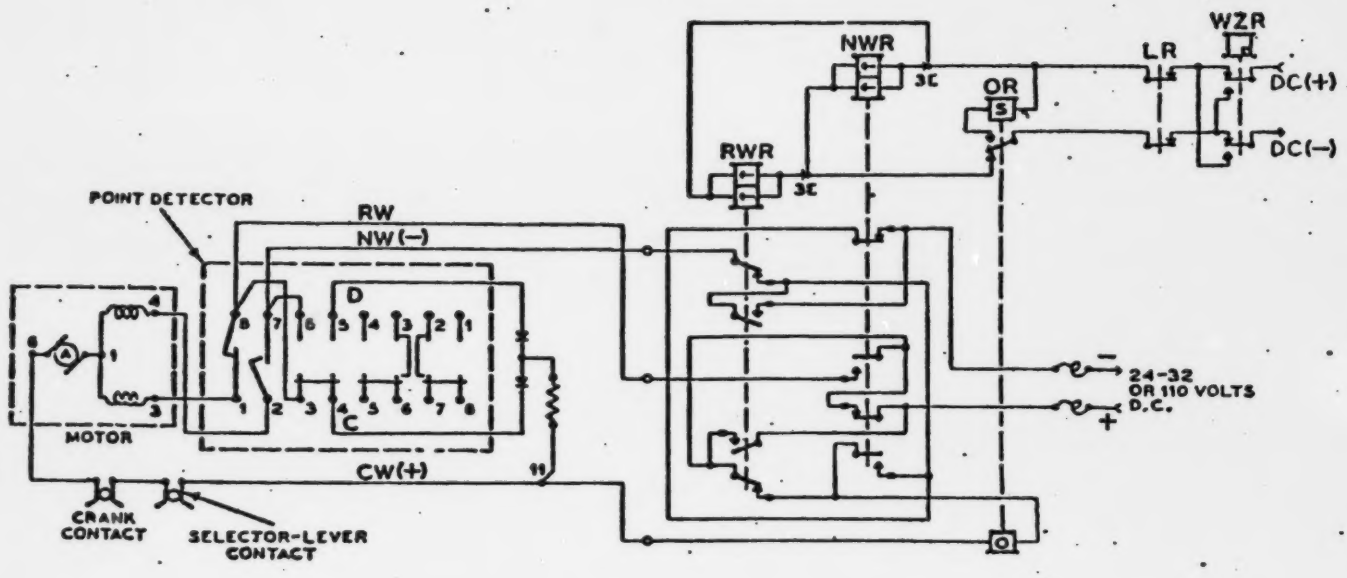


FIGURE 3. GRS MODEL 5F - CONTROL CIRCUITS

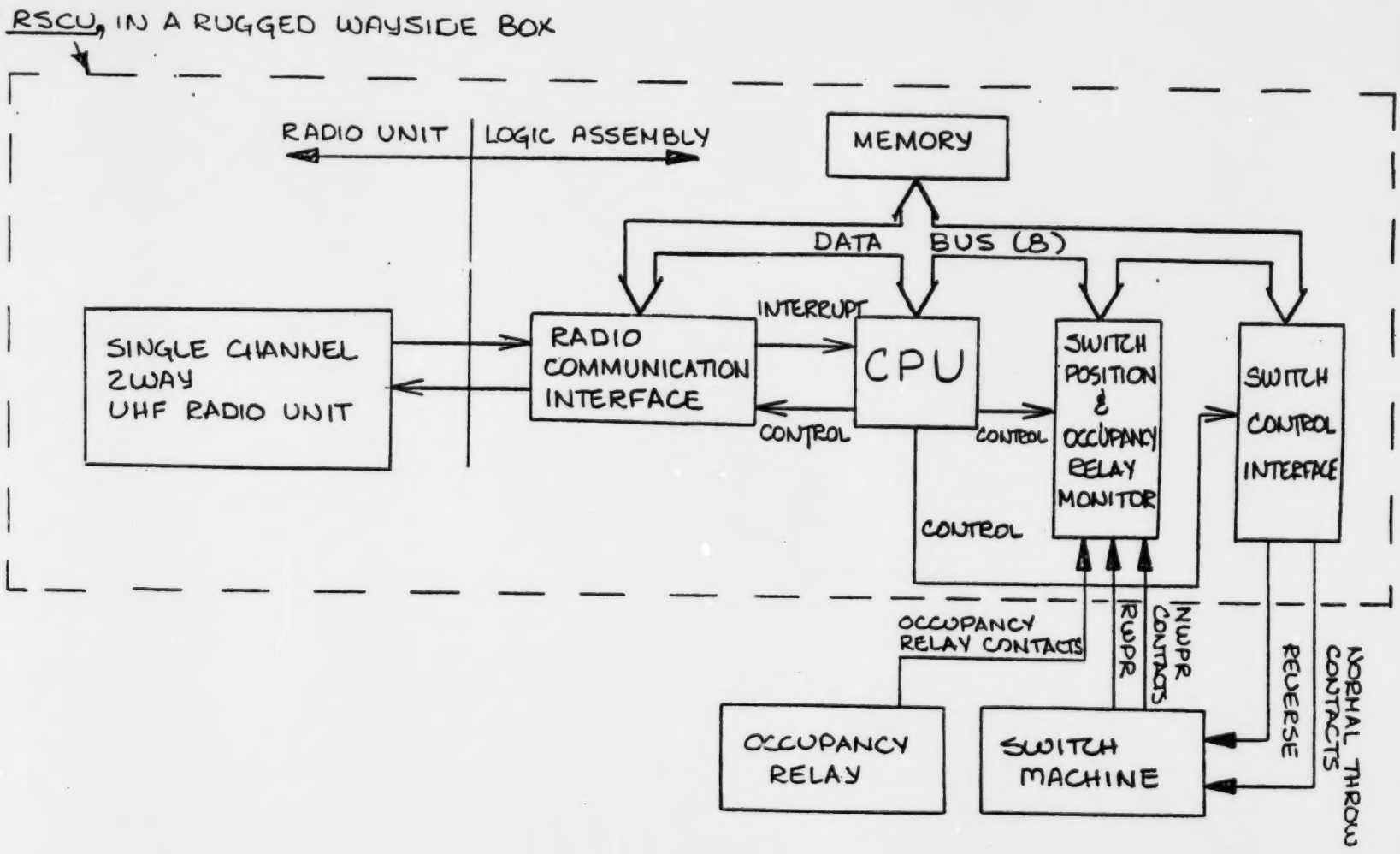


FIG 1. RSCU - BLOCK DIAGRAM

Appendix 'G'

C. P. Rail Draft Operating Specification
Train Control System between Golden and Fording

TRAIN CONTROL SYSTEM BETWEEN GOLDEN AND FORDING

A. OPERATING REQUIREMENTS

1. System to be applied to infrastructure presently in place between Golden and Fording, with the following exceptions;

   - designated sidings at Fernie, Elko and Skookumchuck extended to 8000 feet in length.

   - a new siding installed on Cranbrook Subdivision at Fort Steele, extending 8000 feet eastward from vicinity of Windermere Subdivision junction switch.

2. Present timetable footnotes would apply, except for deletion of the following restrictions:

   - 10 M.P.H. speed limit on specific diesel units on siding Skookumchuck.

   - 30 M.P.H. speed limit on trains handling more than 10,000 tons between Sparwood and Fort Steele.

3. Freight trains would be operated up to 6900 feet in length, comprised of 6 locomotives, 2 of which operate in mid-train slave position, 109 cars and caboose, 14,600 trailing tons. Locomotives on these maximum sized trains would be 3000 horsepower, 6-axle diesel-electric units, equipped with dynamic braking and pressure-maintaining brake valve.

4. Remotely controlled switches, also equipped for hand operation (dual-control) are to be installed at the following locations:

   - both ends of all sidings designated in the timetable except Galloway but including new siding at Fort Steele;

   - Junction switches at Fort Steele and Sparwood;

   - Switches to mine spurs at Elkview, Line Creek and Greenhills;

   - Loop track switch at Fording.

5. All dual-control switch locations are to be equipped for remote operation of switch heaters and employee call signals.

...../2

7. All field equipment shall be designed to operate from standby lead acid battery which is on float charge. Voltages shall be a nominal 2, 12, or 24 vdc. Battery charges for 12 and 24 vdc operation shall be supplied in accordance with AAR Signal Manual Part 244, Requisites for Constant Voltage Battery Chargers. Battery Charger for 2 volt track circuits shall be supplied in accordance with AAR Signal Manual Part on Requisite for Constant Current Battery Chargers. Railway will supply batteries.

8. Electric switch locks, when provided, shall be GRS model 9B or US&S model SL-6A.

9. AC power and communication links will be provided by the railway. Supplier shall provide a list of locations requiring housing installation, ac power, and communication drops.

10. Field hardware shall not encroach upon the CP Rail track clearance diagram.

C. BUDGETARY ESTIMATES

Each proposal must include budgetary estimates in the categories described below:

1. Cost to provide the basic system as proposed.

2. Cost per set of equipment that may be required to be installed on locomotives operating in the system.

3. Cost per set of equipment that may be required to be installed on cabooses operating in the system.

4. Cost to provide a complete standby office computer system to ensure reliability. This is in addition to any redundant computer equipment provided to ensure the integrity of computer links that are vital to the safety of the operation.

5. Costs to provide the system with the ability to detect, and protect movements against, each of the following:

   a) cars or unauthorized movements foul of a main track;

   b) hand operated switches not properly lined;

   c) broken rails;

   d) slide fences tripped.

6. The System is to be controlled from a dispatching centre at Nelson, B.C., which will be equipped with a wall panel model display board (or equivalent) comparable to those used in conventional C.T.C. control centres. The display must include the following indications, derived from information that has been transmitted automatically from field equipment:

   - tracking of all trains and engines in track segments not exceeding approximately 5 miles;
   - track occupancy by train, engine or car, but not by insulated track machines;
   - position of each dual-control switch;
   - switch out of correspondence;
   - power off at field locations;
   - switch heaters operating;
   - employee call actuated;
   - system operating indication from six hot box detectors.

   It must also indicate:

   - extent of all authorities in effect for movement of trains and engines;
   - extent of all track occupancy permits in effect for track machines and/or workmen.

7. Control procedures associated with the System must satisfy the criterion of equivalence with the fail-safe characteristics of C.T.C. in all safety-related areas.

8. The System must be capable of controlling all trains and engines in the territory and, should on-board equipment be required, it must be assumed that no unequipped trains will be operated other than due to an on-line failure.

9. The System shall be designed to permit the operation of insulated track machines, but shall not indicate their presence.

10. The control system must protect fully against any unauthorized entry of a train or engine into the system, any lap of authority or any violation of a track block granted to track machines and/or workmen.

11. The control system must provide for safe operation of following movements into a block.

12. Manual flag protection by trains and engines must not be required for the safe functioning of the System.

13. Dispatcher instructions to govern movements of trains and engines must be transmitted automatically via a vital communications link that requires no response other than a signal that may be used to acknowledge that a new instruction has been received. In effect, voice transmission and repetition of instructions will not be normal in that aspect of the System.

14. The System must be capable of storing instructions to be issued when the route is clear and must ensure there is no delay to trains and engines awaiting instructions that are not otherwise constrained.

15. To facilitate comparison of various systems' expansion capabilities, conceptual proposals should contain specific details, including costs, timing and disruption, associated with the following:

    - adding, extending or relocating a controlled siding;

    - adding, removing or relocating a hand operated switch;

    - inserting a portion of two tracks, each to accommodate traffic in both directions;

    - increasing train speeds to 65 M.P.H.

B. EQUIPMENT REQUIREMENTS

The following list outlines general equipment requirements only, and is not to be considered a specification or a design acceptance. The equipment must be designed to meet railway operating, environmental, and maintenance requirements and at the same time operate safely and reliably.

1. Power switch machines shall be GRS 5F or US&S M23B, installed as per Chief Engineer's Plans T-15-66-1 and T-15-67-1 respectively. Switch machines shall be designed for 24 volts dc operation and low voltage dc control and shall be supplied with necessary connecting rods, point detector lugs, and two 15 watt, 24 vac heaters. In addition:

   a) Control, indication, and overload relays for the switch machine shall be located in the bungalow housings.

b) Track circuits shall be provided for the OS track at turnouts, as described in Chief Engineer's Plan X-18-45, figure 2.

c) Switch circuitry shall be designed to provide:

i) indication of switch position using point detector.

ii) locking of switch when OS track occupied.

iii) locking of switch prior to authority being given to train to approach and proceed over the switch.

iv) an overload relay which stops the switch movement when an obstruction in the point is encountered.

2. Track circuits, when provided, shall:

a) Provide train presence detection with a shunting sensitivity of 0.06 ohms.

b) Be designed on the closed loop principle using two rails, with a transmitter or battery at one end of the circuit and a receiver or relay at the other end of the circuit.

c) Meet a dielectric withstand test of 3000 vac RMS for one minute between track leads, power supply leads, and equipment chassis.

d) Be compatible with existing track circuits used for highway crossings.

3. Wheel detectors, when provided, shall meet the requirements of the AAR Signal Manual Part on "Requisites for Wheel Detectors".

4. Switch circuit controllers, when provided at hand operated switches, shall be GRS model 7k or US&S model U5.

5. Bungalow type housings, not smaller than 8ft. x 8ft. by 7ft. high, shall be supplied prewired at each power switch location. Housings shall be equivalent in quality and features to Chief Engineer's Specification S-0721-1.

6. Signal instrument housings shall be supplied prewired as required for track circuit, wheel detector, transponder, hand operated switch locations, etc.

D. OPERATING DESCRIPTION

Each proposal must include the following information:

1. A complete description of how the proposed system will operate.

2. A complete description of how safety will be assured.

3. Information on operating rules requirements and whether it is anticipated that they can be met within an existing framework such as M.B.S. and/or other sections of the Uniform Code of Operating Rules.

4. A description of the communications facilities required by the system.

5. Information on any required modifications to locomotives and cabooses, including estimated installation times.

6. An explanation of how operations would be sustained under failure conditions.

7. A list of similar installations in North America, indicating length of time each has been in service.

8. A list of similar installations outside North America, indicating length of time each has been in service.

9. Advantages of the proposed system over conventional C.T.C. in areas such as line capacity, efficiency of the system, safety enhancement, fuel savings, etc.

10. Disadvantages of the proposed system in comparison with conventional C.T.C.

11. Benefits of superimposing all or part of the proposed system on an existing C.T.C. installation.

Appendix 'H'

C. P. Rail Manual Block System (MBS)
Special Instructions

SPECIAL INSTRUCTIONS—Continued

MANUAL BLOCK SYSTEM (MBS) SPECIAL INSTRUCTIONS

The following special instructions are supplemental to Rule 323 and only apply on subdivisions or portions thereof specified in the time table or by special instructions.

Wherever the words "Train Dispatcher" or "Foreman" appear herein, they apply to the employee performing the duties.

Wherever the word "Conductor" appears herein, it also applies to a Yard Foreman.

323.1 (a) The movement of trains will be authorized by MBS Clearances which supersede the superiority of trains for both opposing and following movements on the same track.

(b) Trains and Engines may use the main track within Yard Limits as prescribed by Rule 93 and in accordance with Instruction 323.5.

(c) Track units as listed in the time table Special Instruction "N", when accompanied by a Conductor, Yard Foreman or operating officer, may use the main track within yard limits as prescribed by Rule 93 and in accordance with Instruction 323.5 and time table Special Instruction "N".

(d) Train and Engine movements authorized by MBS Clearance must be recorded on the Train Sheet.

(e) Trains and Engines will be designated as:

Extra 234 East
Psgr Extra 234 East
Plow Extra 234 East
Work Extra 234
No 10 Eng 234
First 10 Eng 234 Green Signals
Second 10 Eng 234 Signals Nil
Eng 234 (Within Yard Limits)

Notes:

(i) Track Unit No. will be used as engine when operated as a train.

(ii) A Track Unit may be designated as a train or engine when accompanied by a Conductor, Yard Foreman or Operating Officer.

Engines of other railways will be designated by their initials and numbers as Eng ABC 234, Extra ABC 234 East, etc.

323.2 (a) The Train Dispatcher will issue MBS Clearances, MBS Bulletins and Track Occupancy Permits. Radio may be used for this purpose.

(b) The Train Dispatcher must not issue an MBS Clearance until protection has been provided against conflicting movements and conflicting Track Occupancy Permits.

(c) Where two or more trains or engines are affected, MBS Clearance must first be issued to the train or engine being restricted.

(d) After an MBS Clearance has been correctly repeated, the Train Dispatcher will respond with a "Complete" time and his initials which must be recorded on the MBS Clearance and in the book provided for the purpose in the Train Dispatcher's office.

(e) An MBS Clearance does not become effective until the "Complete" time has been given by the Train Dispatcher and is "Acknowledged" by the receiving employee who will repeat the "Complete" time and the Dispatcher's initials. Should the acknowledgement not be received by the Train Dispatcher, the MBS Clearance must be treated as though acknowledgement had been received but must not be otherwise acted on by the Train Dispatcher until acknowledgement is received.

(f) Additions must not be made to an MBS Clearance after the "Complete" time has been given by the Train Dispatcher except "Call Train Dispatcher" time, if applicable, may be changed.

323.3 (a) MBS Clearances and Track Occupancy Permits will be numbered consecutively each day, beginning at midnight. MBS Clearances once in effect continue so until fulfilled or cancelled. Track Occupancy Permits once in effect continue so until cancelled.

(b) When transmitting each MBS Clearance and Track Occupancy Permit, the Train Dispatcher must write the required information in a book provided for the purpose, reading aloud all applicable written and preprinted portions.

(c) Employees copying an MBS Clearance or Track Occupancy Permit must repeat all applicable preprinted and written portions. The Train Dispatcher must check and underscore each written word and figure each time it is repeated.

323.4 (a) An MBS Clearance which restricts the movement of the train or engine addressed must be sent direct to the Conductor and Engineman of such train or engine. An MBS Clearance which does not restrict the movement of the train or engine addressed, may be sent to another employee. When an MBS Clearance is copied by another employee, it must be delivered to the Conductor and Engineman.

(b) When an MBS Clearance is issued to the Conductor only, he must make a copy for the Engineman. When an MBS Clearance is issued to the Engineman only, he must make a copy for the Conductor.

(c) When an MBS Clearance is sent direct to the Conductor and Engineman, as required in paragraph (a), it must be copied simultaneously by both parties. If the Train Dispatcher is unable to hear the repeat from the Conductor, the Conductor must repeat the contents to the Engineman who must then repeat to the Train Dispatcher and will confirm that the Conductor has repeated correctly. The Train Dispatcher may then issue the "Complete" time.

(d) Conductors and Enginemen are responsible to ensure that other members of the crew have a definite and proper understanding of the requirements of all MBS Clearances and MBS Bulletins as soon as practicable after they have been received. Members of the crew are required, if necessary, to remind Conductors and Enginemen of their contents.

(e) When instructed to "Call Train Dispatcher", the Train Dispatcher must be contacted before the time specified on the MBS Clearance. This time may be changed by the Train Dispatcher as circumstances require. A line must be drawn through the previous time when a new time is shown.

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SPECIAL INSTRUCTIONS—Continued

323.5 (a) When authorized by MBS Clearance, movements may be made on the main track within Yard Limits on the time of First and Second Class Trains.

(b) Movements must not use the main track within Station Limits under Rule 93A except when authorized by MBS Clearance.

(c) When necessary to ascertain whether all First and Second Class Trains have arrived or left, such information will be received from the Train Dispatcher and must be in writing and repeated to ensure correct understanding. The Train Dispatcher must make a record in the book provided for the purpose.

323.6 (a) MBS Bulletins will be issued as required, to give notice of track or other conditions using the procedure prescribed by Instruction 323.2, and must be numbered consecutively, using a separate series of numbers, and re-issued if continuing in effect for a period of two weeks.

(b) An MBS Bulletin will be issued in the application of Rules 4A, 42 and 43.

(c) MBS Bulletins once in effect continue so until cancelled.

(d) Each MBS Clearance issued must show current MBS Bulletin numbers that affect the train or engine addressed. Conductors and Enginemen are responsible for being in possession of each MBS Bulletin. If no MBS Bulletins are in effect the word "Nil" must be shown.

323.7 (a) When transmitting each MBS Bulletin, the Train Dispatcher must write it in a book provided for the purpose and must check and underscore each word and figure each time it is repeated.

(b) An MBS Bulletin to be sent to two or more employees must be transmitted simultaneously to as many of them as practicable. Employees copying MBS Bulletins must, when practicable, check the other repeats for correctness.

323.8 When an MBS Bulletin cannot be transmitted simultaneously to all, or if the repeat from any employee is delayed or is again required, the Train Dispatcher must, when practicable, require an employee who has already repeated to check the correctness of each subsequent repeat. The Train Dispatcher must make a proper record of such repeats. If for any reason an MBS Bulletin is to be rewritten, additional copies must be made from one previously repeated, and repeat to the Train Dispatcher from the new copy each time additional copies are made.

323.9 Flag protection as prescribed by Rule 99 is not required by trains authorized to operate by MBS Clearance, between the points designated, except as provided by Instruction 323.13.

323.10 (a) When stations are used to designate the limits of an MBS Clearance, such authority does not permit the use of the main track between the switches of the siding at either of the stations named unless the MBS Clearance authorizes "Hold main track at _____" or the track is included within the limits of a "Work Between" MBS Clearance.

(b) At stations where no siding is designated, the limits extend to the station name board unless otherwise provided by other special instructions.

(c) When a train stops at the point to which it was last authorized, stop must be made so as not to obstruct an opposing train from using the siding or other designated track.

323.11 (a) A train authorized by MBS Clearance to "PROCEED" from one point to another, MUST MOVE IN THE DIRECTION SPECIFIED ONLY. The Train Dispatcher must be promptly notified when:

— the entire train has cleared the limits specified in the MBS Clearance.

— requested to do so by the Train Dispatcher.

— the entire train has passed points designated in the Time Table or by other Special Instruction.

(b) Within the limits of an MBS Clearance which authorizes a train to "PROCEED" from one point to another the Train Dispatcher will consider the main track CLEAR up to and including the point at which the train was last reported to have passed.

323.12 A train authorized by MBS Clearance to "Work Between" two points may move in either direction between the points named until the MBS Clearance is cancelled.

323.13 (a) Two or more trains may be authorized to "Work between" two points protecting against each other and when so authorized the MBS Clearance must so specify. If protection other than that prescribed by Rule 99 is to be provided, Conductors and Enginemen involved must first have a thorough understanding as to the movements of each other and the protection to be provided. These arrangements must be in writing and repeated to ensure proper understanding.

(b) When a train which is authorized to "Proceed" is instructed to "Protect against" a "Work Extra" such train must not enter the limits specified until instructions have been received in writing from the Conductor and Engineman of the work extra and repeated for correct understanding.

(c) When provision is made for two trains to "Proceed" within the same limits, both the preceding train and the following train must be instructed to "Protect against" each other. Rule 91 applies and if protection other than that prescribed by Rule 99 is to be provided, Conductors and Enginemen involved must first have a thorough understanding as to the movements of each other and the protection to be provided. These arrangements must be in writing and repeated to ensure proper understanding.

(d) In the application of paragraphs (a), (b) and (c), Conductors and Enginemen are responsible to ensure that all members of the crew have a proper understanding of such arrangements before any movement is made.

Should communication fail between the trains involved, no movement is to be made other than that which was last arranged except under the protection of Rule 99.

(e) Snow Plows must not be authorized to operate within the same limits as a preceding train.

323.14 **RESTRICTIONS ON MBS CLEARANCES WILL BE ISSUED:**

— To make provision for a train to move through the limits of a work extra.

— To make provision for two or more trains to "Work between" the same limits.

— To make provision for a following train to "Proceed" within the limits of a preceding train.

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SPECIAL INSTRUCTIONS—Continued

323.15 Should it become necessary to move a train into limits protected by a Track Occupancy Permit, TO ASSIST IN WORK ACTIVITIES, joint authorization between the Foreman in charge and the train must be issued as follows:

(a) All other Track Occupancy Permits within the limits must be cancelled.

(b) The Track Occupancy Permit to the Foreman must contain the words: "Joint authority granted with _____(Train)_____." The Foreman only may authorize this train to enter the protected limits.

(c) The MBS Clearance to the train must contain the words: "Joint authority granted with Foreman _____(name)_____ between _____(location)_____ and _____(location)_____. _____(Train)_____ must not proceed until instructions have been received from Foreman _____(name)_____." Telephone, radio or personal contact may be used.

(d) Other Track Occupancy Permits must not be issued within the limits after joint authority is issued.

(e) Joint authority must not be granted to a train until it has been brought to a stop at the entrance to the limits.

323.16 Before an MBS Clearance is cancelled, a train or engine must be:

— Issued a new MBS Clearance
or
— Stopped within Yard Limits
or
— Clear of the main track
or
— Protected as prescribed by Rule 99.

Cancellation must be sent to and acknowledged by the Conductor and Engineman, who will state the time of cancellation along with their occupation and name, which must be recorded by the Train Dispatcher. The acknowledgement from the Conductor may be relayed to the Train Dispatcher by the Engineman. The Conductor and Engineman must so advise other members of the crew and immediately destroy their copy of the cancelled MBS Clearance.

323.17 When a Train Dispatcher is relieved he must make a transfer of all MBS Clearances, MBS Bulletins and Track Occupancy Permits in effect using procedure outlined in Rule 220, paragraph 4.

323.18 (a) Where MBS Special Instructions are authorized, track units may occupy and/or maintenance work may be carried out on the main track when the Foreman has been issued a Track Occupancy Permit.

(b) A Track Occupancy Permit must not be issued to a Foreman within Yard Limits.

(c) A Track Occupancy Permit does not become effective until the "Repeated" time has been given by the Train Dispatcher and is "Acknowledged" by the Foreman, who will state the "Repeated" time and the Train Dispatcher's initials. Should this acknowledgement not be received by the Train Dispatcher, the Track Occupancy Permit must be treated as though acknowledgement had been received but must not be otherwise acted on by the Train Dispatcher until acknowledgement is received.

(d) Additions must not be made to a Track Occupancy Permit after the "Repeated" time has been given by the Train Dispatcher except "Call Train Dispatcher" time, if applicable, may be changed.

(e) The Foreman must read aloud all Track Occupancy Permits to at least one accompanying employee, when practicable, and ensure clear understanding. Such employee(s) must then be given the opportunity to read and initial the permit.

(f) All Track Occupancy Permits remain in effect until cancelled and, while in effect, protection as prescribed by Rules 40, 41 and 42 is not required between the points designated.

(g) When instructed to "Call Train Dispatcher", the Train Dispatcher must be contacted before the time specified on the Track Occupancy Permit. This time may be changed by the Train Dispatcher as circumstances require. A line must be drawn through the previous time when a new time is shown.

(h) When a Track Occupancy Permit is issued, the Foreman's name, track unit number if any, and the designated limits must be recorded on the train sheet.

(i) More than one Track Occupancy Permit may be issued within the same or overlapping limits. They do not provide protection against other track units or other work activities. Movements must be made at all times in accordance with Maintenance of Way Rules and Instructions Form 568.

(j) Cancellation of a Track Occupancy Permit must be sent to and acknowledged by the Foreman, who will state the time of cancellation along with his occupation and name, which must be recorded by the Train Dispatcher. The Foreman must immediately destroy his copy of the cancelled Track Occupancy Permit and so advise other accompanying employees who have been made aware of the contents.

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Manual Block System Clearance

1. M.B.S. Clearance Number _____ **To** _____ **Date** _____
(Train and/or Engine No.) **At** _____ (Location)

2. M.B.S. Clearance _____ **is Cancelled**
(Number or N/A)

3. M.B.S. Bulletins in Effect _____
(Numbers or Nil)

4.

Do not leave _____ **Before** _____
(Location or N/A) (Time)

After _____ **Arrives at** _____
(Train or N/A) (Location)

5.

This is Authority to: Proceed

From _____
(Location)

To _____
(Location)

_____
(Take siding, hold main track or N/A)

This is Authority to: Work Between

_____ **And**
(Location)

_____
(Location)

Until M.B.S. Clearance is Cancelled

6. Restrictions _____
(As below or nil)

1. **Protect Against** _____ **Between** _____ **And** _____
(Train or Engine) (Location) (Location)

2. **Protect Against** _____ **Between** _____ **And** _____
(Train or Engine) (Location) (Location)

3. **Protect Against** _____ **Between** _____ **And** _____
(Train or Engine) (Location) (Location)

7.

Joint Authority granted with Foreman _____
(Name)

Between _____ **And** _____
(Location) (Location)

_____
(Train Engine No.)

Must not proceed until instructions have been received from Foreman _____
(Name)

8. Call Train Dispatcher _____
(before Time or at or N/A)

9.

Completed at _____
(Time) (Train Dispatcher)

Acknowledged by _____
(Occupation and name)

At _____
(Time)

10. Cancellation

This M.B.S. Clearance Number _____

Is cancelled at _____
(Time) (Train Dispatcher)

Acknowledged by _____ **At**
(Occupation) (Name) (Time)

Acknowledged by _____ **At**
(Occupation) (Name) (Time)

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Manual Block System
Track Occupancy Permit

CP Rail

1.

Permit No. _____ Date _____

Foreman _____ Track Unit or Gang _____
(Name)

At _____
(Location)

This is Authority To Occupy

_____
(Track or Tracks)

Between _____ And _____
(Location) (Location)

2.

Joint Authority Granted with _____
(Train or Engine)

You may instruct this train or engine to enter and/or pass through the limits of this Track Occupancy Permit.

3. Call Train Dispatcher before

Time _____

4. Repeated at

Time _____ Train Dispatcher's Initials _____

Acknowledged by Foreman _____ At _____
(Name) (Time)

5. This Track Occupancy Permit No. ____ is Cancelled at _____
(Time) T.D. Initials

Acknowledged By _____ At _____
(Name/Occupation) (Time)

Note: This permit affords no protection against other track units or maintenance work, nor does it afford any protection against trains or engines in yard limits.

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Manual Block System Bulletin

CP Rail

Bulletin No. _____ **Date** _____

To:

_____

Made Complete at _____ (Time) **Train Dispatcher's Initials** _____

Acknowledged by _____ (Name) _____ (Occupation) _____ (Time)

This M.B.S. Bulletin No. _____

Cancelled at _____ (Time) **By** _____ (Train Dispatcher's Initials)

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Appendix 'I'

C. P. Rail Symbol Trains Timetable

FOLLOWING TIMES FOR INFORMATION ONLY

91	KCN	T.F.	979	67	405	403	445	481	1		2	404	482	XT	984	980	KCS	90
				0540 0500	0410 0325	2055 2010	1830 1745	1405 1320	1440 1355	MT FIELD MT PT PT	1645 1530	2235 2120	1025 0910	2205 2050				
			1900 1915							MT CROWSNEST MT PT PT					1630 1415	0300 0100		
	1300	0300	0030 0630							CRANBROOK					0900 0730	2000 1730	2100	
	2130 0030									GOLDEN							1100 0850	
			1000							KINGSGATE						1400		
		1030 1400								NELSON					0030 2200			
		1630								TRAIL					1800			
1930	0600 0750			1200 1600	0920 0955	0210 0250	0005 0105	1915 2020	1805 1835	REVELSTOKE	1105 1035	1555 1525	0320 0245	1415 1315			0350 0120	0130
0430										KELOWNA								1900
	1330 1445			2330 1330	1500 1515	0750 0805	0605 0620	0140 0155	2230 2245	KAMLOOPS	0625 0610	1055 1040	2215 2200	0815 0800			1930 1815	
	1945 2000			2000 2100	2015 2025	1305 1315	1120 1130	0655 0710	0230 0245	NORTH BEND	0210 0155	0640 0625	1800 1745	0345 0330			1315 1300	
	0015			0100	0025	1715	1535	1110	0600 0610	COQUITLAM	2245 2235	0230	1230	2330			0900	
									0630	SAPPERTON	2215							
									0700	VANCOUVER	2145							